SOUTH AFRICAN GEOLOGY

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BY

E. H. L. SCHWARZ

Professor of Geology at the Rhodes University College,
Grahamstown, South Africa; Late Geologist to
the Geological Commission, Cape Colony;
Author of "Causal Geology"

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PREFACE

I have endeavoured in this little book to give a short résumé of geology from a South African standpoint. A volume of this sort has long been wanted, and it has not been written before because it was necessary that the writer should have a first-hand knowledge of South African geology, and also experience of the difficulties that beset the South African student in interpreting geological nomenclature. The climax was reached when, in a class lecture, I said that in the desert springs have no brooks: I was greeted with a shout of laughter. It took me a long time to see the point; but once seen I sat down and proceeded to write the present volume. Brooks are unknown in South Africa; if a spring does happen to come out of the ground, its water is carefully led away by a furrow into a dam or on to irrigated land, or it trickles away and is lost in the sand. The only brooks that the South African student knows of are the Dutch equivalent for trousers. I have, therefore, tried to express in phraseology that is familiar to the South African student the main facts about the science. I have been tormented by two factors which have proved very troublesome. The first was that the size of the volume had to be reasonably small, and a hundred-and-one subjects lured me on to write prodigiously upon them; the second was that the book had to be orthodox, for college students who are supposed to read this work in preparation for their examinations are faced with external examiners, whose limitations I know, for I was one myself when on the Geological Survey. I have, however, put in some material which is still on the side of unrighteousness; for example, the Planetismal Hypothesis. As this is accepted all over America, and is taught in at least two universities in England, I could not in justice to the science insert the old exploded Nebular Hypothesis, with its mediæval visions of fire and brimstone. Brun's work on volcanoes is still in the expensive French edition, and is unknown to most geologists, yet his work is too thorough to permit of doubt but that the steaming-volcano people are wrong. In the case of the igneous rocks I have allowed myself to dilate on the absorption of sedimentary rocks in defiance of *ex cathedra* statements that basic selvages to laccolites are due to magmatic differentiation; but here I have such unmistakable proofs that my reading is correct that it would be misleading to instruct the South African student otherwise, when by looking out of the railway carriage he can see for himself the facts of the case. In the stratigraphical part I have been guided by the present state of the geological surveys, and have put in all the separate systems of Pal-Afric rocks, though I believe that half of them are only modifications of the other half. Teachers will have to indicate where their views differ from mine, but the scheme here presented will, I think, help the student to grasp the main principles better than a mere cataloguing of isolated facts.

Some people collect postage stamps, others, called geologists, collect facts and docket and label them with an intelligence equal to that devoted by the stamp collectors to their subject. My book will be of very little use to those who wish to become scientists of this kind. I have endeavoured to describe the facts as far as possible in relation to their causes, and to give some insight into the processes of geological reasoning. I have used the simplest possible language, because I hope that the book may fall into the hands of many people who, though not skilled in all the intricacies of scientific nomenclature, take an interest in nature and have a longing for a better understanding of the glories of this wonderful land of South Africa.

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SECTION I

DESCRIPTIVE GEOLOGY

Definition of Geology.—The Science of Geology is concerned with the study of the Mineral Kingdom, and therefore is a science parallel with Zoology and Botany, which are concerned respectively with the Animal and Vegetable Kingdoms. Like the two latter sciences, Geology deals with specimens—mineral or fossil species—which can be examined in the laboratory; but there is a far larger sub-section of the science which deals with specimens in the bulk, minerals aggregated into rocks, and rocks aggregated into land masses, continents, islands, mountains, and so forth; and all these must be considered in relation to the globe as a whole. A great part of Geology is thus concerned with vast masses which cannot be examined at leisure in the study, but which must be investigated in the field, and our ideas about them must be formed gradually as experience accumulates and our travels show us more and more of the diversities of the earth's surface. In this lies at once the disadvantage and the fascination of Geology. In our inability to see the whole of a mountain range or a continent, we formulate certain theories as to their nature which are probably erroneous, and have to be altered continually as new facts come to light—so that Geology lacks the definiteness of the other sciences, in which the subject-matter can be put into bottles, and is a halfway house to those abstract sciences like Ethics, Psychology and so forth, where the subject-matter consists of images and ideas which have no concrete existence. On the other hand, the subject-matter is so vast that anyone who takes up the work seriously is presented with a field of observation and research that can never be exhausted, and even one who has but a casual knowledge of the science can find subjects of unending interest in any and every locality in the wide world.

Theories about the origin of the earth, the mountains, the valleys, the seas, and the lakes have been formulated from time immemorial, but the modern science dates from the teaching of two men—Werner and Hutton. Abraham Gottlieb Werner was appointed professor of mineralogy at the Freiberg School of Mines in Saxony, in 1775; he rapidly became famous, and men from all parts of the world assembled in his classroom to hear him lecture on Geology. His principal thesis was that all rocks had been deposited from water, and that even the crystalline rocks had so originated when the sea was practically a chemical solution in the beginning. Hutton, however, who was by profession a doctor of medicine in Edinburgh, found that the crystalline rocks had been intruded in a molten state into the aqueous or sedimentary rocks, and in 1788 he published his *Theory of the Earth*, in which he set forth his views. Werner's theories were described as those of the Neptunian school, as the central idea was aqueous deposition; Hutton's theories, on the other hand, were called those of the Plutonian school, as the most outstanding feature in them was intrusions of rock which were supposed to have come up to the surface of the earth molten with the heat of the nether regions, over which Pluto was supposed to reign. The rival theories were debated with great heat and incredible bitterness. The Neptunists, because their primordial ocean, in which the rocks were formed, seemed to have some connection with the Noachian deluge, were judged to be on the side of righteousness, whereas the Plutonists, although they were able to show ample evidence for their views, were looked upon as followers of Antichrist, because their theories ran counter to the Book of Genesis. Time has softened the bitterness, but has not removed all traces of the quarrel. The Plutonists won the day, and still hold the upper hand, but it is becoming apparent that the central heat from which they derived their molten rocks is a myth, and Werner's solution theory of crystalline rocks is not only a tenable theory, but one more in accordance with physical laws. This century-old controversy is typical of geological work at the present day; the evidence appeals to different people in different ways, and each view contains some portion of the truth. The elements of all geological problems are so complex that dogmatic assertion can find no place in the science. Geology teaches one to weigh evidence and to arrive at conclusions which must be based on wide knowledge and logical reasoning for them to have any value. The beginner misses the artificial aids to knowledge rendered in other sciences by measurements and numerical estimates, and the predominant note at first may appear to be given by the mass of apparently vague and conflicting data. After a while, however, the main issues of the science become clear enough, and the method of reasoning in the end will be found to be as accurate as that employed in the physical sciences, although the geologist cannot support his findings by mathematics.

South African geology differs from European or American geology, which is the subject-matter of most textbooks of the science, in that South Africa is a fragment of a southern world-segment which, in many respects, is different from the continents which are found in the northern hemisphere. The differences in the rocks themselves we shall deal with in the special part, but in the general part also there will be found considerable divergence from the usual treatment. This is necessary because the conditions in South Africa are not the same as those in Europe and America. South Africa is a young country, geologically speaking; there are no navigable rivers; the action of frost is negligible, while desert conditions are frequent; on one side the influence of the tropics is apparent on the coast, while on the other the currents from the Antarctic make themselves felt; the land borders the sea with an almost straight coast line, there are no inlets of any size, and the central plateaux lie far removed from the influence of the sea—these and other differences are reflected in the character of the face of the earth revealed in South Africa, and a textbook to be of use in this country must deal with facts as they exist. It is not, of course, that the fundamental laws as worked out in Europe and America have no application here, but the features that occur so rarely in these countries, that they require no mention in textbooks, are prominent here, and vice versa.

The Cosmical Aspects of Geology.—Underlying most geological reasoning is the conception of the origin of the earth which we happen to have adopted. Until recently the earth was supposed to have cooled from a state of incandescent liquid. The commonest form of this theory is the Nebular Hypothesis. On this theory the solar system was conceived to have been one originally in a state of gas, which on cooling began to revolve. The particles of matter fell in towards the centre owing to contraction and gravitation, but were also thrown outwards by the centrifugal force, on the principle of a stone whirled at the end of a string. The particles at the equator of the revolving sphere, where the motion was most rapid, became subjected to two opposing forces, one causing them to fall in, the other causing them to fly out, and it is supposed that at a certain stage the two forces balanced, and the equatorial belt was left self-sustaining in space. The rest of the gaseous matter continued to contract, and at various stages further rings of matter were left balanced, until the central mass was enabled to contract as a whole. The central mass became the sun, and the rings of gaseous matter after a while cooled sufficiently for the gas to become a liquid. At this stage the rings snapped, and the matter became aggregated in liquid balls, which followed the paths of the parent gaseous rings; thus were born the planets, of which the earth is one. Finally, the liquid balls cooled sufficiently for the surface to solidify, and a crust or outer shell of solid rock was formed over a molten interior. This is the state in which the earth is supposed, on this theory, to be in at the present time. The theory explains so simply the phenomena of volcanoes and the ridging of the crust into mountain ranges due to the crust having to follow the shrinking nucleus, that it has been very generally accepted in the past.

The great French mathematician Laplace worked out the theory mathematically, so that at the time it appeared to be dynamically possible; but the knowledge we now have of gases makes it improbable that such a gaseous ball could have existed and have revolved at such a terrific rate, for as we now know the gaseous matter would have diffused through inter-stellar space. From the geological side, also, the theory has been attacked, especially from the evidence afforded by earthquakes; in these the tremors pass through the centre of the earth and can be recorded on the other side, where they show that they have passed the whole distance through solid substances of high rigidity. Volcanoes and folded mountain ranges can also be quite well explained, supposing the earth to be solid. A new theory, making no use of a central molten nucleus, became necessary, and this was proposed by T. C. Chamberlin in 1905: it is called the Planetismal Hypothesis, because the earth is supposed to have been formed by the infalling of fragments of solid matter floating in space like the actual planets, and hence called planetismals, or little planets. A great deal will have to be done before the Planetismal Hypothesis can be finally accepted as proved; but as it accounts for more facts than the Nebular Hypothesis, and, so far, no fatal error has been discovered in it, as in the Nebular Hypothesis, we must accept it as our basis. The theory is that as meteorites or shooting stars fall upon the earth, and many of them arrive solid on the surface, it is quite possible that in past ages they not only fell as now, but fell in greater quantity. Some 20,000 tons of meteoritic matter fall upon the earth annually, and there is no doubt that the earth is growing, although very slowly. If now we conceive a swarm of meteorites, produced perhaps by the disruption of a sun that has grown cold, the individual blocks would tend to aggregate by gravitational attraction, and directly one little aggregate became formed it would act as a centre of attraction for the other outlying fragments, and thus it would grow rapidly.

The central point of the original swarm of meteorites is represented now by the sun, the smaller aggregates by the planets, and the original fragments by the comets and shooting stars which still are being attracted by the larger aggregates. The theory has been tested mathematically by F. R. Moulton, and is dynamically possible. If we accept it we must be prepared to explain all our evidence without the help of a hot interior of the globe.

The Temperature Gradient in the Earth's Crust. — On the Nebular Hypothesis the interior of the globe is very hot, and therefore the crust resting upon it should show evidence of this by becoming warmer the deeper we bore into it; and this is actually the case. A great many measurements in differents parts of the globe have been made with a view to ascertaining the average rate of increase as one goes downwards, and one degree of Fahrenheit for every sixty feet seems to be in round numbers a fair average. That is to say, below the surface layer, the temperature of which varies according to the heat it receives during the summer and winter from the sun's rays, there is a continuous rise of temperature as far as we have been able to penetrate the earth's crust. If the surface layer is at a temperature of 60° F., 60 ft. below the bottom of this layer the temperature will be 61° F., 600 ft. below, 70° F., and 6000 ft. below, 160° F., and so on. The variations in temperature gradient at different places, however, is very great, ranging from an increment of 1° F. for every 30 ft. to 1° F. for 254 ft. In the British Isles there is an increment of 1° F. for every 55 ft. at London, 1° F. for 34 ft. near the Scottish border, and 1° F. for 92 ft. in the south of Ireland, with every gradation between the two latter in different localities. In one shaft alone, at the Rose Bridge Colliery, at Wigan, between the levels 1674–2445 ft., the rate of increase varies from 1° F. for 24 ft. to 1° F. for 110 ft. In South Africa data are very scarce; in the Karroo the rate of increase is approximately 1° F. for every 100 ft., and on the Witwatersrand 1° F. for 254 ft.[1] On the Nebular Hypothesis all these variations would be due to the varying nature of the rock, which in some cases allowed the heat from the interior to leak out quickly, in others obstructed the outflow of heat; an average, therefore, of all the variations would give approximately the average leak and from this average temperature increment the depth at which any temperature could be obtained could be calculated. Thus at 30 ml. a temperature of something like 2500° F. would be obtained, taking the increment to be 1° F. for 60 ft.; at this temperature steel melts and most rocks would be fused. Again, with this average increment of temperature it is possible to calculate the time when the earth first cooled sufficiently for a crust to form on the surface, the *consistentior status* of Lord Kelvin, because the temperature increment gives an estimate of the rate at which the heat of the interior is being dissipated. The over-crusting of the liquid globe has been calculated to have happened from 60 to 100 million years ago.

[1] This is the result of forty determinations, down to 4400 ft. J. Whitehouse and W. L. Wotherspoon: *Jour. Chem. Metal. and Mining Society*, South Africa, Johannesburg, vol. xi, 1911, p. 534.

On the Planetismal Hypothesis the centre of the globe is cold, and these deductions from the temperature increment must therefore be wrong. In the first place the crust of the earth contains within itself sources of heat which render it self-heating. These are, (*a*) chemical changes produced in the rocks by circulating water, (*b*) movements which cause segments to grind against each other and yield frictional heat, and (*c*) all rocks on the surface of the earth contain radium which spontaneously gives out heat.

(*a*) Chemical changes are accompanied either by the giving out or by the absorption of heat. In rocks containing pyrites or iron sulphide the chemical action which reduces the mineral to an oxide is accompanied by considerable heat, so much so that when the rock containing the pyrites contains coaly matter the heat evolved is sufficient to ignite the mass. Such a case has happened many times round the Kimberley mines, where a black carbonaceous rock is exposed near the surface. The mining operations have opened up large quantities of the black shale, which has thus been brought into contact with water from rain; decomposition sets in, and consequently the shale catches fire and has in some instances continued to burn for many years. The Black Lias of Yorkshire and Dorsetshire catches fire in a similar way and from the same cause. The extraordinary variations in the Rose Bridge Colliery shaft above-mentioned are due to a similar cause; where chemical action is considerable the temperature increment is rapid, where it is less the increment is small. Pyrites occurs universally in rocks, and its oxidation serves as a type of chemical action which gives out heat. In the lower depths of the earth's crust the reversed action goes on: chemical changes occur which absorb heat.

(*b*) Movements of extraordinary magnitude have occurred in the earth's crust. At Worcester, Cape Colony, for instance, a segment of the earth has slipped down vertically 2 ml., and faults of like nature occur throughout the country. In the Highlands of Scotland and in the Alps great segments of rock have been bodily thrust 10 ml. horizontally over other rocks, and in every mountain range similar movements have taken place. These movements are very slow, so that the heat produced by them is spread over a vast period of time; nevertheless they are in progress to-day as they have been in the past, and are yielding a constant supply of heat to the earth's crust. All movements in the crust do the same; earthquakes, for instance, which heave the ground, produce a certain amount of frictional heat. In the Charlestown earthquake of 1886 it has been calculated that a force of 1,300,000 h.p. was expended over an area of 100 sq. ml., and all this energy was dissipated as heat.

(*c*) Radium occurs in all rocks of the earth's crust. The Hon. R. J. Strutt found that granite from Rhodesia contained 9·56 tons of radium in every billion tons of rock, or, say, 200 lb. of radium per cubic mile.

A ton of radium will give out, during its half-life of 1760 years, heat equivalent to that produced by a million and a half tons of coal burnt during that time. Taking granite as the typical rock forming the crust of the earth below the covering of sedimentary rocks, and assuming the crust to be 30 ml. thick and the area of South Africa, including Rhodesia, to be 1,235,000 sq. ml., the slice of the earth represented by South Africa is being warmed by radium by an amount equal to the consumption of 9 million tons of coal a day. This rate of evolution of heat is sufficient to explain the whole of the temperature gradient in the earth's crust, assuming that it receives no heat whatever from the internal nucleus. If the centre were hot the added heat would render the earth's surface uninhabitable.

In the second place the temperature gradients, while dependent on the radium content of the rocks in the neighbourhood and on the chemical action going on in them, show generally that the older the rocks—that is, those that have been once deeply buried and have been nearer the earth's centre—the slower are the gradients, as on the Witwatersrand, where the increment is 1° F. for 254 ft.; but the more recent the rocks the more rapid does the increment become, so that we must assume that the increment as one goes deeper becomes less and less, until at a certain stage no further rise takes place, and from here downwards to the cold centre the temperature decreases. Where the zone is in which the temperature increase stops is a matter of speculation; it is probably not more than 20,000 or 25,000 ft. below the surface. It is this fact, quite inexplicable on the theory of a hot earth centre, that nearly stopped the boring of the Simplon tunnel through the Alps, because the granite encountered belonged to the younger rocks of the earth's crust and the temperature gradient was rapid; whereas in the Witwatersrand mines, where the temperature gradient is small, owing to the rocks being extremely old, the temperature at the bottom of the even deep levels is moderate enough to allow working.

The Size and Shape of the Earth.—The size of the earth was first measured by an African, Eratosthenes, a priest of the temple of Syene (Assuan), in Egypt. At this place there was a religious festival on the day when the sun shone vertically at noon, and consequently threw no shadows. One year Eratosthenes happened to be in Alexandria on the day in question, and as this town lies 2000 stadia to the north of Syene, the sun's rays were not vertical, but threw shadows. The angle the vertical made with the sun's rays gave the angular distance between Alexandria and Syene, which Eratosthenes found to be $7\frac{1}{5}$ degrees. Assuming the earth to be a perfect sphere, 2000 stadia divided by $7\frac{1}{5}$ gives the length of 1 degree of circumference, and this, multiplied by 360, gives the total circumference of the earth. This calculation is sufficiently accurate for most purposes; actually the earth is not a perfect sphere but is flattened at the poles; roughly, however, we may say that the distance from the surface to the centre is 4000 ml.; of this 30 ml. is the crust, with which we, as geologists, have to deal.

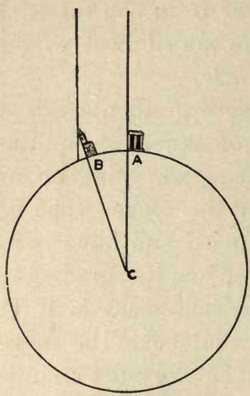


Fig. 1.—Eratosthenes' Measurement of the Globe

The sun's rays being parallel, when the sun is vertical at Assuan, A, the walls of houses will throw shadows at Alexandria, B. The angle the sun's rays make with the walls of the houses is equal to the angular distance ACB. Knowing the distance AB, this divided by the number of degrees of the angle ACB and multiplied by 360 gives the length of the circumference of the globe.

Besides being flattened towards the poles the earth's shape is irregular, in that the Pacific Ocean forms a great flattened depression on that side of the globe, as in the thick end of a pear, while the continent of Africa forms a mass projecting above the normal surface on the op-

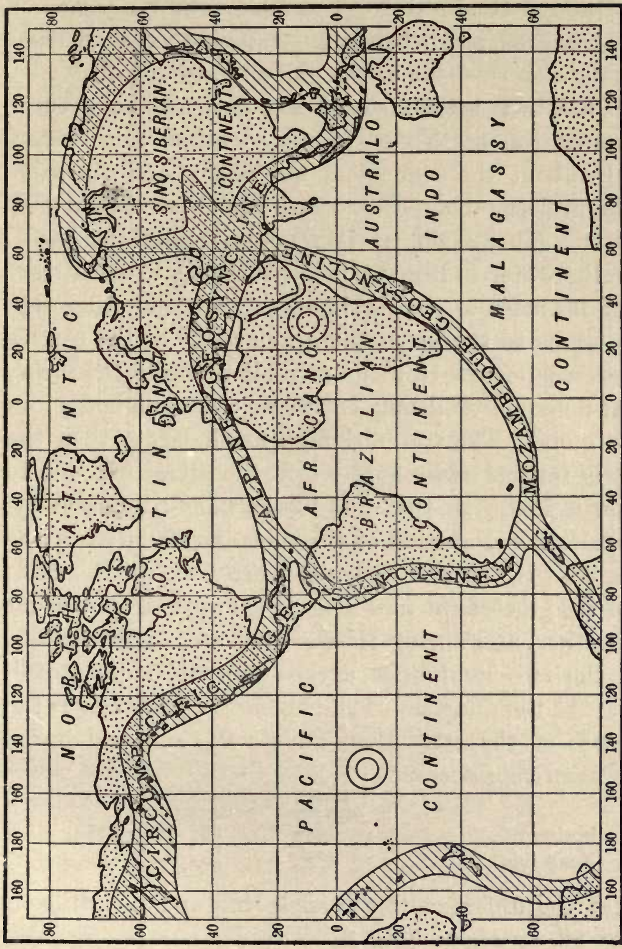


Fig. 2.—Map showing the Geosynclines or Zones of Movement in the Earth's Crust (after Haug). The circles are placed on the stalk of the pear and on the base of the pear respectively, according to Jean's theory of the shape of the earth

posite side, as in the stalk end of the pear. The actual shape of the earth is not yet known. A line from Cape Town through Central Africa to Palestine, and from there through Russia to Nova Zembla, is in the course of being measured, and when it is completed we shall have better data on this side of the globe to argue from.

The Relation between Land and Sea. — The greater portion of the earth's surface is covered with water, roughly about three-quarters are ocean, and the continents project above the ocean basins as broad flat plateaux. The moon, as it revolves round the earth, causes the water to heap up below it, owing to the attraction of its mass to the liquid mass. On the other side of the globe to the moon the gravity due to the earth's attraction is lessened by the attraction due to the moon, so that an equal tidal bulge of water occurs on both sides of the globe. The sun, although much larger than the moon, is farther away, and hence the attraction due to the sun is less than that due to the moon; numerically, if we take the attraction of the moon as 100, that of the sun is 38. If the sun and moon are both on the same side of the globe, as at new moon, then the two attractions act together, and spring tides occur; the same happens when the two luminaries are on opposite sides at full moon. At the quarters of the moon the joint tide is the difference of the attractions due to the sun and moon, when neap tide occurs.

	Moon's Attraction.		Sun's Attraction.		
Spring tide	100	+	38	=	138
Neap tide	100	−	38	=	62

So that the difference between spring and neap tide is 138 to 62, or about 7 to 3.

If the sun and moon can exert such an attraction on the waters of the globe, the continents, which are close at hand, must equally attract the water, and hence the ocean surface does not conform to the shape of the solid globe, but is curved upwards towards the continents. In other words, were the attraction of the continents on the water of the ocean to be done away with, the sea round the coasts would sink several hundred feet, and the continents would stand so much higher above sea level.

An alternative view has been held, which supposes the water in the ocean basins to be kept in place by denser rock forming the floor of the oceans; the rock forming the continents is about 2·6 times as heavy as water, whereas the sub-oceanic crust has been supposed to be three times as heavy. This necessitates that the oceans have always occupied more or less the same place. This has been disproved, and it is now certain that just as the continents have been covered repeatedly by the ocean, so the ocean floor as often has been exposed as dry land. The Permanence of Ocean Basin Theory, therefore, is no longer tenable, though it was powerfully advocated by Dana and Wallace.

The Atmosphere.—Surrounding the globe is an envelope of gas consisting principally of oxygen and nitrogen, but carrying also carbon dioxide and water vapour in notable proportions. This atmosphere enables plants and animals to live, but it has also a profound influence on rocks, and its action is called "weathering". On the surface of the moon, which has no atmosphere, the rocks stand up clear and unaltered, though they have been exposed for countless ages; a slight alteration is noticeable in some of the mountains of the moon, which is ascribable to the splitting of the rocks under the influence of the alternating heat and cold of the moon's day and night. Our day is much shorter than the moon's day, and the variations of temperature are consequently so much less, yet everywhere we see the rocks crumbled and worn by weathering, and this is due to the action of the atmosphere.

The atmosphere consists of—

	By Volume.	By Weight.
Oxygen	20·91 ...	23·115
Nitrogen	79·06 ...	76·840
Carbon dioxide	·03 ...	·045

The amount of water vapour is extremely variable, being very slight in desert regions and very high in the moist tropical regions. Besides these there are the minor constituents, the gases argon, krypton, xenon, neon, helium; solids, ammonium chloride from volcanic eruptions, sodium chloride from the salt spray of the oceans, nitrates due to the combination of nitrogen and oxygen by the electric spark (lightning), and various floating particles, volcanic dust, dust from the burning of falling stars, dust swept up by the wind from deserts, and even microscopic plants and the spores of plants.

The oxygen is the prime agent in the atmosphere; it has a chemical affinity for most things and will unite with them, forming oxides. The simplest case is that of iron, which rusts or oxidizes on exposure to the atmosphere; the most important case, however, is its union with carbon. This may be brought about directly with the aid of heat, as when coal burns, but it also takes place if the carbon or a compound of carbon is exposed in minute particles to the action of the oxygen, as in the case of the blood in animals, and the tissues of plants, in both of which the waste carbon products are burnt off at a comparatively low temperature. The surface of the earth breathes much as an animal does; down all the little cracks and crevices on the surface there is carried water containing a certain proportion of oxygen, and there, in the extended surfaces of the cracks, the rock substances are exposed to the action, and the compounds forming the rocks become oxidized. The simplest case of this is the oxidation of the blue colouring matter of rocks, which is a sulphide of iron; on the surface of the earth these rocks are usually coloured red or yellow, the blue sulphide having been converted to the red or yellow oxide of iron.

In a large number of cases oxidation of compounds in the rocks renders them soluble, so that when the rain descends on the weathered rock it washes away a certain proportion of the substance in solution, and the rest, becoming loosened by the removal of the cementing material, crumbles away and is washed down the hill-side as sand.

Nitrogen is an extremely inert gas, but under the influence of the bacteria a large amount is fixed as a compound of oxygen. Organic life could not go on without nitrogen compounds, but the geological action of nitrogen is insignificant. Saltpetre, formed by decomposing animal matter, is really an organic product, and the only original mineral nitrogen compound of any importance is the ammonium chloride which escapes explosively from liquid lavas and forms the dense white cloud that accompanies volcanic eruptions.

Carbon dioxide is of extreme importance. It is expelled in enormous volumes in all volcanic explosions, but it is absorbed rapidly by the plants, which are able to use it for building out of it a more complex carbon compound called cellulose, which is the basis of wood and indeed of all vegetable tissue, and hence of all the coal, anthracite, and graphite of the rocks. The waste products of cell activity in plants are got rid of by oxidation, so that the plants are able to use over again the carbon dioxide; but this is a subordinate action in plants, in animals it is the condition of their existence, and all animals are breathing out carbon dioxide continuously. The amount of carbon dioxide given off by animals in the process of respiration, added to the artificial production of carbon dioxide in the burning of fuel, is, however, insignificant as compared with the amount poured out by volcanoes.

Another means for abstracting carbon dioxide from the atmosphere is that of limestone formation. Vast numbers of animals, such as shell fish, corals, and so forth, and a few plants, have the power of secreting their carbon dioxide combined with lime, so that the carbon dioxide is not returned to the atmosphere but is laid by indefinitely. It follows, therefore, that a volcanic epoch is one in which the atmosphere is being supplied with a superabundant amount of carbon dioxide, whereas a period of intense limestone formation, as happened when the chalk of England was formed, or a period of coal formation, means an excessive abstraction of carbon dioxide from the air. The one follows the other, and in past geological ages the volcanic epoch has been followed by tropical conditions over the whole globe, so that trees such as the cinnamon and magnolia have been enabled to grow within the Arctic circle, and forests have flourished in the Antarctic; whereas the limestone periods and the coal periods have been followed by glacial conditions. The Carboniferous Period, when most of the great coal seams of the world, in America, Europe, and China, were formed, was followed in the Southern Hemisphere at least, certainly in South Africa, by an Ice Age, when the streams became frozen and glaciers filled the valleys.

The action of carbon dioxide in affecting climate rests on a simple physical basis; the gas is readily penetrated by the direct rays of the sun, but the heat waves reflected by the earth are stopped, so that the carbon dioxide forms a blanket which keeps in the warmth received from the sun. The other constituents of the atmosphere have similar properties, but to a less extent, and it is the carbon dioxide which has had a controlling influence on climate in past times.

Water vapour is dissolved in the atmosphere, and the warmer the air the more water vapour can it hold. When a warm mass of air is brought into contact with colder air, the moisture held in the former can no longer be held dissolved, and hence it condenses and falls as rain. The familiar form of this is when the barometer falls: the cold upper layers of the atmosphere are brought lower, and round the edge of the depression the warmer air near the earth is cooled and rain falls. Water vapour is absorbed into the atmosphere in two ways: (*a*) from the surface of the ocean and other bodies of water; (*b*) from transpiration of moisture through the pores of plants, and also from the corresponding breathing and perspiration in animals. Most of the water absorbed from the ocean is precipitated back into the ocean as rain; the water vapour from which most of the land rains are derived comes from the transpiration of plants. A field covered with lucerne or meadow grass gives off some 400 lb. of water a month from every square yard; wheat and other cereals about half as much; and potatoes, vines, and such like about 50 lb.; oak and fir forest about the same. It is evident, therefore, that the more cultivation there is, and the more forest there exists in a land, the more rain will there be. In South

Africa, owing to the dry climate, most of the indigenous plants have special apparatus for stopping transpiration, and the cultivated area is practically negligible, so that whereas in normal countries only 30 per cent of the rainfall on land is derived from the sea, and the rest supplied by the land itself, in South Africa we have to rely principally on the sea for our rains. In other words, we could in South Africa increase our rainfall by something like 70 per cent if the waste lands were cultivated.

In regard to the solid particles in the atmosphere, they exist in enormous numbers. A special apparatus for counting them was devised by Dr. Aitken and used in Melbourne. The volume of air taken was a cubic inch, and the lowest number recorded, on a wet day, was 128,000 particles; the highest number was two million. In the eruption of Krakatoa, in 1883, the island, some 6 ml. long by 3 wide, with mountains 2500 ft. high, was blown up into the air, and soundings of 164 fathoms are obtained where it once was—a little crescent-shaped islet, a mile long, is all that remains. The dust thrown into the atmosphere by this explosion remained suspended for many months and floated completely round the world. But besides such paroxysmal upheavals, the atmosphere is constantly being invaded by dust; winds, especially in South Africa, carry the sand for long distances, but the finer particles remain suspended and float about for months. Where ponds and vleys dry up, the weeds perish and the microscopic life which frequently swarms in them is killed, and the dead bodies of these and particles of the dried-up plants may be carried over wide areas. In 1902 a fall of black rain was recorded in Kimberley. Some of the residue from the water collected from the roofs of the houses was put under the microscope, and a quantity of quite recognizable organisms were discovered, the commonest being *Sarcina coli,* a bacterium which lives in the intestines of animals.

Generally, the atmosphere extends upwards for about 45 ml., at which height the barometer would stand at less than 1 in.; meteors burn at heights up to 200 ml., but the air is so rarefied beyond 45 ml. that it is scarcely worth while considering it. If concentrated to a uniform density, such as it has at sea level, the atmosphere would extend to a height of 5 ml. The pressure of the atmosphere is taken as unity: it is equal to a pressure of 14·73 lb. on every square inch, and it will support a column of water 34 ft. high (30 in. of mercury, as mercury is 13·59 times heavier than water).

The origin of the atmosphere, on the Planetismal Hypothesis, is due to the gases brought to the earth in the meteorites out of which it is formed. Actual meteorites contain a large amount of gas, principally carbon monoxide, carbon dioxide, marsh gas, hydrogen, and nitrogen, and this may be taken to represent the constitution of the original atmosphere. On the fixation of carbon from the carbon oxides and marsh gas, free oxygen and hydrogen were produced, which, uniting, gave water, and the surplus of oxygen and the nitrogen remains in the atmosphere to-day.

The watery envelope, or hydrosphere, is the liquid covering of the earth. When the water vapour condenses from the atmosphere it falls as rain; about a quarter of this runs off into the drainage channels, eventually forming rivers, which flow to the oceans, or into depressions on the land, where the water evaporates. About three-quarters of the rain that falls sinks into the ground, where it is used by the plants and in part makes its way by underground channels till it reaches an outlet where it can escape to the surface again as a spring, or descends lower and lower and becomes absorbed in rock-forming minerals.

Rivers.—If we imagine a continent to have newly risen above sea level and for the first time to have been exposed as dry land, the surface will be a featureless plain and the first rain that falls will flow away in broad sheets of water to the ocean. As time goes on, the inequalities of the surface will be taken advantage of, and the flowing water will gradually follow definite channels, which in course of time it will deepen by carrying away the mud and sand, so that the course of the river will become more or less fixed. The course of the early rivers will be a meandering one, as there will not be much fall to induce the water to rush straight to the sea. In general the rivers will form systems leading by common main channels to the ocean, the smaller branches being called tributaries of the larger channels. The area of one stream system is a drainage area, or if regard be had to the rain that falls it may be called the *catchment area*. The ridge surrounding one catchment area is called the watershed. The level of the sea forms a base-level below which the river cannot cut, so that if the supposed newly formed continent is only elevated slightly above the sea, and remains stationary for a long while, the rivers will become stagnant and tend to form lakes, marshes, and great winding curves in their courses. If now the continent rises again, the rivers immediately will tend to cut downwards. The rivers will still follow the courses determined by them in the first flat surface, so that a number of winding gorges will result, and each river course will be separated from the next by a stretch of flat ground. Such is the case in South Africa, although most of the plateaux owe their origin to other causes than those supposed in this hypothetical case we are following. Successive rises in the continent will give successively greater fall to the rivers, and, if they are rapid enough, the rivers will only cut downwards, and the gorge-like nature of the river valleys will be perpetuated. If, however, the continent remains stationary after a succession of rises, the rivers will cut downwards to base level, and then, as their power of cutting downwards has reached a limit, further action will be directed towards cutting sideways; the banks will be undercut at the outer edges of the curves, and silt and mud will be deposited on the insides of the curves, so that eventually there will result a broad valley bordered with flats covered with all the debris washed down the river, which is called, collectively, *alluvium*. As time goes on, the steep sides of the rock banks of the river crumble from the attacks of weathering, and rains wash down the sides, carrying all loose material into the bottom of the valley. Eventually this process goes on till the slopes leading into the valley are cut back till they meet the slopes of the adjoining river, and the watershed between the two rivers is no longer a flat stretch but a crest; the topography of the country is said to have become mature. Tested by this criterion South Africa would be said to be a young country with immature topography, whereas Europe would be an old country.

The extreme case of river action is where the continent remains stationary so long that the crests between the rivers disappear, the rivers cut sideways and eventually level the whole land once more to a featureless plain; such a surface is called a *peneplain*, where the whole country is said to be base-levelled. Instances of peneplains are everywhere in evidence in the coastal regions of South Africa, some of the best being found in Oudtshoorn, Uniondale, and round Grahamstown. The flats are still covered with river material, which often has become hardened. As the continent rose subsequently to the peneplanation, the rivers began to cut downwards once again, and sawed out valleys on the plains, so that one sees the original peneplains high up above the river valleys and the edges abruptly cut off at the commencement of the slope. The peculiar table-topped hills covered with hardened river sand are very characteristic of South African coastal landscape; this must not be confused with the table-topped hills in the Karroo, where the cause of the tops being level is quite different.

If the ground over which a river runs is soft, it will tend to wear it away rapidly, and if it is hard it will cut through it slowly; hence, if there is a bar of hard rock in the midst of soft ground the river receives a check. Two cases are presented: in the first the bar is too hard for the river to remove, hence the bar will act as a temporary base level and the river cannot cut below this in its reaches above; the result is that the country above the rock lip is peneplained, and where the water pours over the bar a waterfall is produced. Admirable examples of this occur in South Africa in the Victoria Falls, where the rock bar is a sheet of basalt, and at the Augrabies Falls, where the Orange River pours over a bar of granite. The flat country of the north-west of Cape Colony and the Orange Free State owe their features to peneplanation to a base-level determined by the granite of the Augrabies Falls. The second case is where the river is sufficiently powerful to cut through the bar: the softer rock on either side is removed, and the bar emerges as a mountain; the course of the river continues the same and its valley forms a gorge in the mountain. The finest scenery of Cape Colony is due to this latter cause: the great coastal mountains are cleft with stupendous gorges. At Meiring's Poort, through the Zwartberg range in Oudtshoorn, the mountains on either side rise to 7000 ft. and the level of the river is 1500 ft., the walls in many cases being almost perpendicular.

When the hardness of the bar is about equal to the cutting power of the river, the latter forms a lake or vley behind the bar.

If there are two rivers running parallel, and the one runs over soft ground, but the other runs over hard ground, or has a bar in its course, the former will lower its bed more rapidly than the latter. The drainage area of the one river will tend to enlarge more rapidly than is the case with the other river, and it may happen that a tributary of the lower river may eat back so far as to draw off the water from the upper part of the river in the higher level. This frequently happens in nature, and the process is called *river capture,* the river with its head waters drained into another basin is said to be *beheaded.*

The greater the slope the more the water tears down it, and the more gravel and shingle will it carry to wear away its bed. On the side of the mountain the torrents wear out their beds very rapidly, but directly the same rivers emerge on to the plains at the foot, the slope is rapidly flattened, the carrying power of the rivers is decreased, and the wearing power lessened; hence rivers flowing from mountains in this way tend to eat back into the hills by what is called *head-stream erosion.* The carrying power of the river depends greatly on the slope; on the mountain-side great masses of rubble and big boulders may be carried down, but once the river reaches the plain the small gradient reduces the carrying power of the river, and the stones and rubble are left behind at the foot of the hills. In the Karroo this feature is found everywhere, and it is essentially a characteristic of semi-desert regions, because in humid regions the action of rain and rivers is more continual and gradual.

In mountainous regions the soil, if there is any, or the bare rocks become occasionally so crumbly by prolonged droughts that when the rain falls it is absorbed as if by a sponge. After a while the crumbled material becomes surcharged with moisture and turns into a quicksand. Being on a slope, the quicksand begins to flow, carrying with it large boulders, and the whole mass rolls down the hill like a lava stream, overwhelming any obstacle, such as houses and trees, in its path, and producing an incredible roaring, as the rocks embedded in the semi-liquid mass grind against each other. When the mud-rush comes to the plains it spreads out harmlessly, and after a while the sand drains away or is washed away by subsequent rains, and there is left behind a trail of great blocks of rock, which are known as stone rivers. On the Karroo hills these are familiar objects, and they are made the more prominent as the moisture retained in them causes a luxuriant growth of bush on the sides of the stone rivers. In the coastal country the mud-rushes are often occasioned by bush fires; the soil becomes dried and exposed, vegetation no longer binds it together, and the first heavy rain causes one of these disastrous avalanches.

Where the country is covered with sand the water simply sinks in, and does not run away by any channel visible on the surface; a large portion of it evaporates and leaves a crust of calcareous tufa beneath the sand. Such a condition is found in Bechuanaland and the Kalahari, and to a large extent in the north-west of the Cape Colony, south of the Orange River.

South African rivers are to a large extent intermittent rivers; even the great Zambesi and Orange Rivers are extremely variable in their flow, though they never actually dry up. The smaller rivers frequently dry up entirely, and when the rain comes, the whole run-off is carried impetuously away to the sea. Supposing, now, that the water which falls in the storm is not enough to fill the whole length of the river channel: where the storm breaks there will be an excess; the river will overflow its banks, and cause a wide temporary vley to form. As storms break more or less in the same place season after season, the temporary vley becomes marked by a bare stretch of silt-covered ground. Such widenings of the river channels are called *vloers.* The storm passes away, the river ceases to flow, but certain pools remain where the river bed is deeper; these are called *kolks.*

Pans.—If now the storms do not yield enough rain to flow past the vloer for many years in succession, the lower part of the river may become obliterated and a pan results. This of course can only happen in semi-desert regions, where the crumbling of the rocks of the surface goes on vigorously, and the particles are blown away by the winds. A typical pan may be a few hundred yards, or 20 ml. across as at Verneuk Pan in Kenhardt. In many cases their connection with a river can still be traced, either in the elongated form or by the fact that a particularly heavy rain will cause them to overflow their lip, and the water will find its way to some neighbouring river channel. In many cases the pans appear to be quite isolated hollows; but their history, nevertheless, is in all cases the same. The pans are for the most part very shallow, and the mud covering their bottoms is very fine, tenacious clay, useless for anything, and in addition it usually contains salt. All rocks contain a certain amount of lime, soda, chlorine, and sulphur, and as these are soluble, the result is that rainwater, washing down from the rocks, absorbs a certain amount of these substances. If the river has free access to the sea, the water contains such a small amount of these dissolved substances that it is fresh; but the continual pouring of these substances into the ocean, and evaporation of the water, has, in the course of ages, caused the ocean to become salt. The same happens on a smaller scale where year after year water containing small amounts of salt and lime washes into the pans; the water evaporates and a concentration of the salt and lime takes place, and in many instances crystallizes out naturally as salt and gypsum. The inland salt pans, which occur all over the western part of the Orange Free State, as at Haagenstad, and in the north-west of Cape Colony, are different from the coast salt pans. These latter are shallow depressions in marine gravels and sands, which still retain some of the actual salt of the sea; and as the rain washes through the porous material it dissolves a small amount and carries it to the depression, where, in the course of years, it accumulates. Two interesting pans of this nature occur near Port Elizabeth: one at almost sea level at Bethelsdorp, and the other in the raised beaches, at an elevation of about 300 ft. The Pretoria salt pan owes its salt to the ordinary rock weathering, but the origin of the depression is probably due to volcanic action.

The mouths of rivers where they debouch on the sea are accompanied by certain characteristic features. In lands where the topography is mature, and the sea floor slopes gently downwards, the mud and silt collect about the mouth of the river and cause the formation of a delta. A good example is the Nile delta: the sand has collected to such an extent that the land has advanced considerably into the Mediterranean, and the river finds its outlet through numerous channels in the delta. In South Africa both conditions for the formation of deltas are absent. In many cases, as in the Great Fish River, enormous masses of mud are discharged during a flood, enough to colour the sea for miles; but the steep coast is swept with swift currents which carry the sand away, and deposit it all along the sea bottom. In the Orange River the channel loses itself among the sand dunes, and rarely opens on to the sea directly; but again the formation of a true delta is prevented by the current that washes up from the Antarctic. The opposite extreme to a delta is a drowned river valley: the rock channel of the river has been cut with more or less steep sides, according to the time the river has been employed in fashioning its valley, and then, on the land sinking, the sea invades the land and flows up the channel to a considerable distance. Large numbers of South African rivers are of this type; at the Kowie River, in Bathurst, the tide flows up to 12 ml. from the mouth, and similar conditions exist in most of the rivers flowing into the Indian Ocean. Very few rivers flow into the Atlantic Ocean in South Africa. Where the river is perennial the fresh water meets the salt water and mingles with it, producing brackish water, which is characteristic of most of the waters of estuaries in well-watered lands; but the estuaries or tidal portions of the South African rivers are filled with almost pure salt water for the greater portion of the year, as the rivers flow intermittently, and are frequently dry for months or even years.

As sand is being carried continually up and down the shore, by coastwise currents, it tends to accumulate in the openings formed by the rivers, and builds up *bars*. These may be simply tracts of shallow water at the mouth of the river, on which the waves break, and which may be swept away by a flood coming down the river, or they may accumulate so much that they entirely cut off the river from the sea, in which case lagoons are formed. Such is the nature of the famous Gxaxa lagoon. The Durban and St. Lucia Bay lagoons are similar, but the channels between the lagoons and the sea are still open to a certain extent, and in the case of the former the channel has been widened artificially by dredging.

Boulders and pebbles rarely reach the mouths of the rivers, as the grinding along the course of the streams is sufficient to reduce them to sand, and what is eventually discharged is fine sand.

The river system of South Africa is a very simple one. On the south, where alone it has been properly studied, there is a central ridge, elevated 6000 ft. above sea level, which runs from Cape Town to Delagoa Bay.

The waters originally flowed from this ridge symmetrically on either side, over a featureless plain. As the land rose the straight courses of the rivers were preserved, and though, by the carving away of softer rock, mountains rose as if to bar the way, the rivers were able to cut through them at a sufficient rate, and they were, therefore, not diverted. In the east, however, a great chain of volcanoes broke out, which piled lavas across the courses of the southerly flowing streams, forcing their waters to flow back and over the main watershed. Those streams are now collected into one main channel, the Orange River, and this breaks across the main watershed at Aliwal North, the only breach in the watershed throughout its entire length.

The rivers always carry a certain amount of gravel and sand with them, which becomes deposited where the river current is slack. In the head reaches of the rivers, where they flow down the mountain-side, blocks of all sizes and shapes fall into the river course, and are moved according to the volume and rate of flow of the stream. The largest are soon left behind, but the residue is carried down stream and dragged along the river bottom. In the process the larger boulders become rounded by grinding against each other, and the bits ground off go to swell the mass of sand; the boulders also grind against the bottom of the river and erode it, producing more sand. The finest particles and the mud are carried in suspension, and are usually carried right out to sea; but the sand and gravel fill the beds, and are shifted downstream at every flood, or may be banked up on the side of the stream and form alluvial flats in the rock channel.

Glaciers.—In cold climates, and in hot ones where the land is sufficiently elevated, instead of rain falling, the moisture is condensed as snow. This accumulates on the mountain-sides, and instead of rushing impetuously downhill, slowly slides down, consolidating itself into ice in the process. When it reaches a depression, the moving ice forms a definite river of ice or glacier, which continues to flow down till it reaches a warmer level, when it melts and gives birth to an ordinary river, or

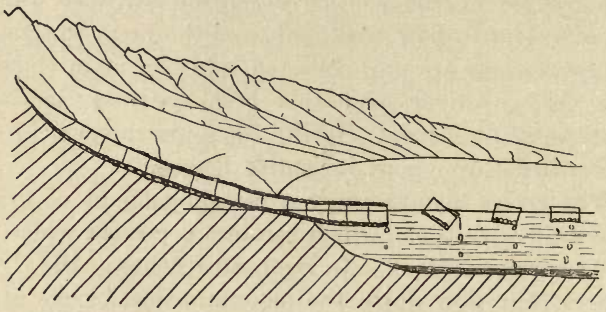


Fig. 3.—Diagram showing a glacier reaching the sea, icebergs being calved from off it, and the morainic material being dropped, on the melting of the icebergs, into the mud on the bottom of the sea

it reaches the sea and pushes its nose out into the water. In the latter case blocks of ice are broken off by the waves, and these float off as icebergs. The top of the glacier, where the snow is consolidating, is surrounded by precipitous cliffs which are continually being riven by the frost, and blocks fall on to the *névé* or *firn*, as the consolidated snow is called, and are carried down in the moving mass, sinking deeper and deeper as they travel, till eventually they reach the bottom, where they accumulate as a ground moraine. This is dragged along the bottom of the glacier somewhat like the sand at the bottom of a river. The same takes place on the sides of the glacier, and consequently the sides of the ice stream become covered with fallen blocks, some of which sink through the ice, but others remain on top, forming what is called the lateral moraines. If two branches unite into one glacier, the inside lateral moraines of the two separate glaciers become the central moraine of the larger stream. If the glacier reaches a level where

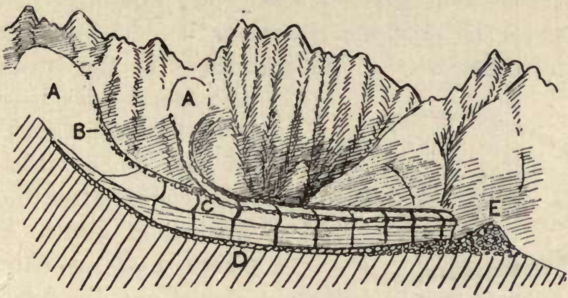


Fig. 4.—Diagrammatic Section through a Glacier

A, Glacial cirques, or collecting grounds for the snow, filled with "névé" or "firn". B, Fallen blocks, forming a stream of stones on the side of the glacier, lateral moraine. C, Median moraine, formed by the coalescing of the lateral moraines. D, Ground moraines, formed of blocks that have worked their way to the bottom of the ice. E, Terminal moraine. The crevasses are shown.

it melts, the water, having much less carrying power than the ice, leaves the boulders behind, and the accumulation of these is called the terminal moraine. If, however, the glacier reaches the sea, the icebergs calved from off it carry the boulders out to sea frozen in them; and when the icebergs eventually melt, the boulders are dropped into the mud deposited on the sea floor. We then have a marine boulder clay or till. The terms, *boulder clay* or *till*, are otherwise used to denote any accumulation of morainic material. The boulders carried by the ice are pressed against the sides and bottom of the valley, which they score with characteristic grooves, and cause the valley to assume a **U**-shaped curve quite different from the **V**-shaped outline of the ordinary river valleys. The boulders themselves are ground flat on one or more sides, according as they have been forced to turn in their bedding of ice, and the surfaces are scored with sets of parallel scratches. Such facetted and ice-scratched boulders are very characteristic, and can never be mistaken for river boulders or boulders of any other origin. Several times in the history of the world glacial conditions have come over parts of the globe which are now warm; after the Coal Period, in South Africa, there was an extensive glaciation; the ice-scored valleys can still be seen in Prieska and the southern Transvaal, and all south of this there is found the Dwyka conglomerate, which is partly a terrestrial, partly a marine boulder clay. In Europe and America the Great Ice Age occurred when man appeared first on earth, and the whole of the country thus glaciated is now covered with a thick covering of boulder clay. There was no corresponding Ice Age at this time in South Africa, but it occurred in New Zealand and in the south of South America.

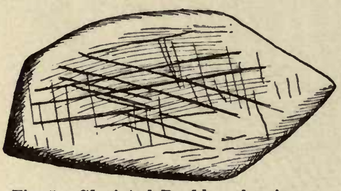


Fig. 5.—Glaciated Boulder, showing one side facetted or smoothed, and covered with series of parallel striations

If there are hard projections in the course of the glacier, these may project through the ice and form a sort of island, which is called a *nunatuk*. If, however, the ice surmounts the obstruction, it becomes characteristically marked; the side which lies facing the movement is called the *stoss* side, because it receives the brunt of the pressure, and is consequently deeply

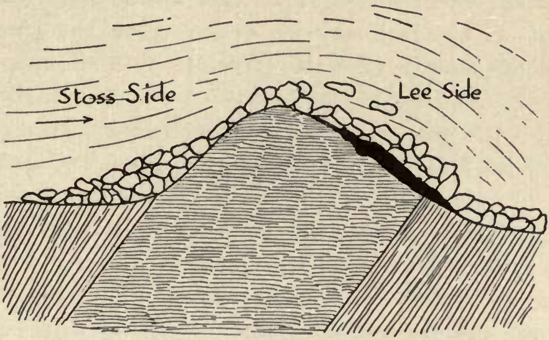


Fig. 6.—Roche Moutonnée, showing the ice, carrying ground moraine, pressing against a bar of hard rocks and polishing and rounding it on the stoss side

scored by the boulders held in the ice; the *lee* side, facing downstream, is unscratched, because the ice bends over it and does not touch it. These rounded

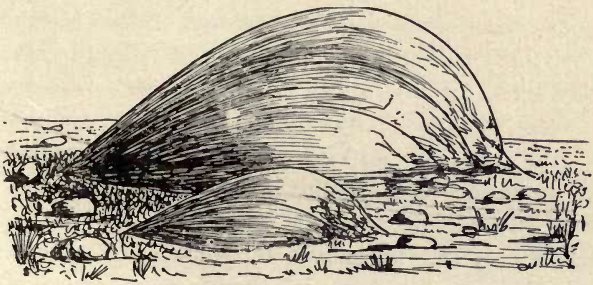


Fig. 7.—Roches Moutonnées, showing the surfaces rounded and polished on the side the ice sheet moved from (stoss side), and rough and irregular on the lee side.

hummocks are called *roches moutonnées,* because the stoss side is covered with smooth ridges separated by deeply scored hollows, and these together give the appearance somewhat of the back of a wig formed of long rolls of horsehair. The roches moutonnées give the direction from whence the glacier has flowed, and are important, as the ordinary ice scratches on the glaciated pavements simply give the direction without indicating which way the ice moved.

Under the glaciers there are often sub-glacial streams, and the sand carried by them forms, when the ice melts, long, winding ridges; the moraines also often break through the tops of the tunnels of the sub-glacial streams, when boulders are added to the sand. Such ridges are called *kames* and *eskers*. There is an interesting case in Bechuanaland of a somewhat similar train of boulders called Blink-klip breccia; this is rock that has tumbled into an underground river in limestone by the breaking of the roof.

Lakes.—On a high coast it frequently happens that enormous accumulations of sand occur, and between the firm land and the dunes there is a depression. The Knysna lakes are a good illustration of this kind; they are partially salt, from communication with the sea, and partly fresh, from drainage from the land. Even when the water of the lakes is quite salt, almost fresh water can be obtained by sinking wells in the sand round the edge, a feature also found in the Trona lakes, in the Lake Chad region.

Lakes may also be formed by volcanoes, the chimneys of which serve as hollows for the reception of rainwater; in other countries, where the volcanoes have long been extinct, the actual craters become filled with water from subterranean springs. The top of the peak of Tristan da Cunha is occupied by a crater lake. Again, portions of the earth may subside between faults, and leave a depression which may become filled with water, as at Lake Tanganyika in the Great Rift Valley, and the Dead Sea, but these will be discussed later on in connection with faults.

The salt of pans and lakes is usually common salt with an admixture of gypsum; in Palestine the two are mixed, so that a block of salt may "lose its savour", that is, all the salt may be sucked out and only gypsum may be left behind. In all the South African salt pans the salt crystallizes out separately in a layer above the gypsum. In North Africa there is a great quantity of sodium carbonate in the lakes; this comes up in springs, and is not of superficial origin. Such a sodium carbonate spring occurs at Palapye, in Bechuanaland. In Egypt the ordinary washing soda or natron has been obtained from time immemorial from the natron lakes in the Suez region. A natron lake occurs also in the Western Rift Valley, east of Tanganyika. In the Lake Chad region the substance is the bicarbonate of soda, trona. Elsewhere, as in Tibet, in the Great Salt Lake of Utah, and in the lagoons of Tuscany, borax is contained in the water, but in these cases the springs which contribute the substance to the lake waters are connected with volcanoes.

The highest lake in the world is Titicaca, 12,576 ft., lying under the giant volcanoes of the Andes, Illimani, and Sorata, each 21,000 ft. The lowest lake is the Dead Sea, 1286 ft. below sea level. There are not many lakes below sea level—Lake Assal (−566 ft.), in Abyssinia, is an example. If the flow of river water into the Black Sea were to be stopped by desert conditions coming over the land, the level of the sea might fall far below sea level, as the Black Sea lies in a basin over 7000 ft. deep

(1185 fathoms have been recorded), and the outlet at the Bosporus is not deep. As a matter of fact, the surface of the Caspian Sea, which is just such a lake without outlet, and lies in a region of small rainfall, is 86 ft. below sea level. A similar thing might happen to Lake Baikal which, though it lies 1500 ft. above sea level, is 4748 ft. deep where the Trans-Siberian railway crosses it.

Oceans.—The rivers that discharge their water into the oceans account for their existence, for the water cannot flow elsewhere, as the ocean basins are the lower portions of the earth's crust. There has been a theory that the water of the oceans is due to extrusion of original water vapour from the interior of the globe; but this depended on the supposition that volcanoes discharged vast quantities of water vapour during their explosions. Lately Brun has investigated the exhalations of volcanoes and found them to contain no trace of moisture, so that this theory falls to the ground.

The rivers carry with them a large amount of matter in suspension; the fine solid particles of mud subside very slowly in fresh water and the current of the river is sufficient to keep most of this from settling, so that it is discharged into the ocean. The mud settles quickly in salt water, but the incessant motion of the sea is sufficient to keep it moving, and thus this fine material is carried far out from the shore. The greatest distance mud can be carried from the shore is 200 ml. The heavier sand, which for the most part is dragged along the bottom of the river, is also discharged into the ocean, and is swept up and down the coast by the currents; but as a rule it is not carried beyond a few miles. These two classes of rock waste, the sands and the muds, form the floor of the ocean within 200 ml. of the coast. They are known as the marine sediments, and when hardened and consolidated are known as sandstones and shales, which form the bulk of the sedimentary rocks. Besides these mechanical sediments, as we may call them, rivers carry substances which they have dissolved out of the rocks; all river water will, on analysis, yield quite perceptible amounts of various salts. We can find the salts in river water, and by measuring the discharge of the river we can estimate the amount of salts removed annually from the land drained by the river. In round numbers the average is as follows:—

Amount of Substances removed Annually in Solution from the Land Surfaces of the Globe (Mellard Reade)

	Average per Square Mile.
Calcium carbonate (limestone)	50 tons.
Calcium sulphate (gypsum)	20 ,,
Sodium chloride (common salt)	8 ,,
Silica (quartz or ordinary sand)	7 ,,
Carbonates and sulphates of soda and potash ...	6 ,,
Magnesium carbonate	4 ,,
Oxide of iron	1 ton.

Silica and iron are not found in sea water, though both must exist in minute traces; but the rest are found somewhat changed in the salt evaporated from sea water.

Composition of Sea-salt (Dittmar)

Calcium carbonate	·345
Calcium sulphate	3·600
Sodium chloride	77·758
Sulphate of potash	2·465
Magnesium, chloride, bromide, and sulphate ...	15·833

The proportion of sodium chloride to the salts of lime is 8 to 70 in the river waters, but in the sea it 77 to 4.

This means that the sodium chloride is not used up in the sea, but simply accumulates from year to year; the lime salts on the other hand are made use of by countless myriads of sea animals. On the coast we have shell fish and corals secreting lime to form their hard parts, and in the open ocean there are forms of microscopic life which do the same. The surface of the ocean swarms with animals and plants which are barely visible to the naked eye, but which show under the microscope many remarkable forms. The principal of these are the Foraminifera, of which Globigerina is the commonest type. They are animals consisting of little rounded masses of jelly, which are enclosed in a hard shell of calcium carbonate. With them, and affording a part at least of the food supply of the Foraminifera, are the microscopic plants called Coccoliths, also possessing hard parts made of calcium carbonate. These two sets of organisms multiply with great rapidity, and, when dead, sink to the bottom of the ocean in a continuous rain, so that the deep ocean becomes covered with a sediment, though of quite another type to that of the shore sediments: it is typically a limestone. The slimy matter not yet consolidated into rock is called an ooze; this substance is found adhering to the leads used for sounding in the deep ocean. When the ooze is examined it is seen to consist of the dead shells of the animals which may be caught living in a tow net on the surface. Consolidated ooze is chalk, and ordinary chalk will still show the original Globigerinas, though a large portion is made up of broken fragments.

The reason, then, why so little lime salts are found in sea salt is that the substances are constantly being abstracted by organisms.

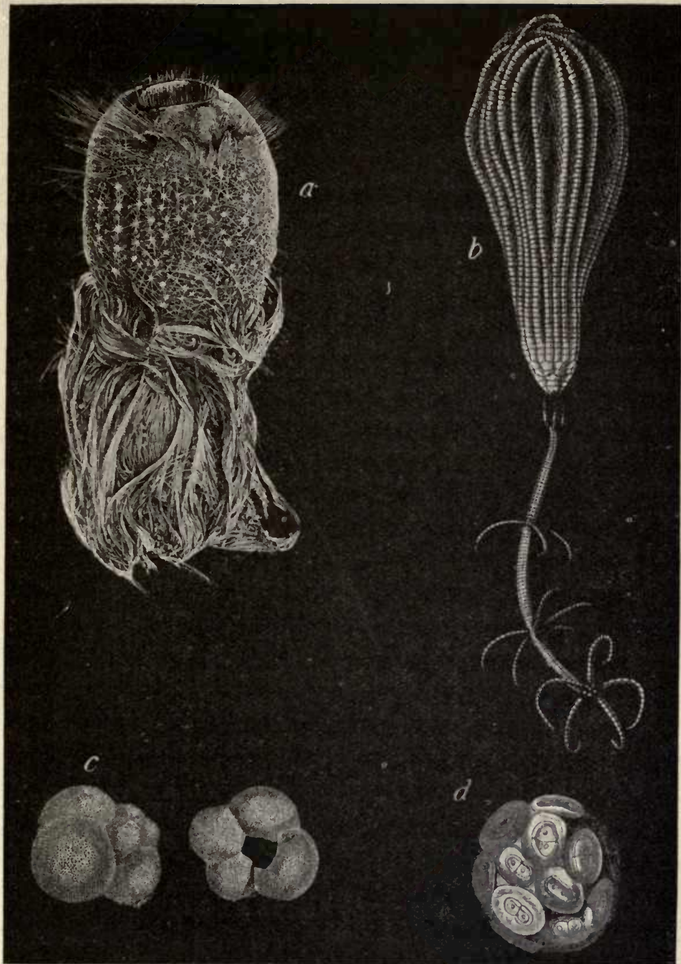


Fig. 8.—Forms of Life that contribute to the Organic Deposits in Deep Oceans

a, *Holtenia carpenteri*, Wyville Thomson, a siliceous sponge, the spicules of which go to form the flint nodules in chalk and the bands of chert in dolomite. *b*, *Pentacrinus wyville-thomsoni*, Jeffreys, a crinoid that yields calcium carbonate to the sediments. *c*, *Globigerina bulloides*, d'Orbigny, highly magnified. The dead shells are shown as they fall to the bottom of the sea. *d*, Coccosphere, made of coccoliths very highly magnified. *c* and *d* are free-swimming organisms that yield the greater amount of calcareous matter to the deep-sea oozes which consolidate as chalk. (From Professor Wyville Thomson's *Depths of the Sea*, Macmillan & Co.)

The same applies to the silica, which cannot be detected in sea salt, but which is there in minute quantities, and every molecule of which is in demand by organisms which have the power of making their hard parts of silica—the animals are called Radiolaria and the plants Diatoms. These live with the lime-secreting animals, though in lesser number, and are approximately of the same size. When the sea is very deep indeed, the calcareous shells become dissolved as they sink into the regions of great pressure, and only the fine insoluble residue eventually settles. This is known as *red clay*, which covers the floor of the very deep oceans in many parts of the world. The silica of the Radiolaria and Diatoms may similarly be left over by the solution of the calcareous shells of the Foraminifera and Coccoliths, and a siliceous slimy mass may result, which consolidates as chert, or if it forms lumps and nodules it is known as flint.

The iron enters in part into the living tissues of the organisms, but a great deal of it combines with the dissolved silica near the coast and forms a green silicate of iron, known as *glauconite*. Off the Agulhas Bank the Globigerina shells become filled with this glauconite and the shells subsequently dissolve, so that the sand dredged up consists of little rounded casts of the Globigerina shells in glauconite. Glauconite sand when consolidate is known as *greensand*, and forms a considerable portion of the rocks of Cambridgeshire, the Isle of Wight, and elsewhere.

The magnesia is not used up by the animals or plants, yet the comparison of the amount discharged by the rivers, and that existing in sea water, shows that it is being laid by somewhere. Now, no precipitation of the salts in the ocean is possible except by organic agency. The magnesium salts, however, compromise by uniting with the calcium salts after the animals die, so that half the latter are set free again to be used by the living animals. This process of combination of calcium and magnesium salts is known as dolomitization, and the chalk or coral rock, instead of remaining a pure limestone, becomes a dolomite. All natural limestones contain a certain proportion of magnesium. This process is continued, after the sediment is hardened into rock, by the adding of magnesium by water circulating from the surface downwards.

In some places the surface of the ocean, owing to the cold or from other unfavourable circumstances, is devoid of life, and then the floor receives no deposit, except the very finest dust, which results from the burning meteorites (cosmic dust) and volcanic dust.

The floor of the ocean being for the most part covered with sediment of some kind—shore, deep sea, or abyssal—is more or less flat; but in reality it is simply a sunken continent, the islands being the tops of mountains; and the valleys can to a certain extent be recognized by soundings in spite of the covering of sediment. Very careful surveys of the ocean floor have been made by the cable companies, and we know now that the ocean floor is far from being a featureless plain. Round the borders of the continents there are shelves beneath the sea, from which evidence can be obtained, in the form of river boulders, and continuations of the river gorges, that they were once dry land. The most noteworthy of these is the 100-fathom plateau on which the British Isles stand, and a ledge submerged to the same extent is also found on the other side of the Atlantic. In South

Africa a similar ledge borders the land. It is at its widest south of Cape Agulhas, and is about 90 fathoms deep; beyond it the sea floor sinks rapidly to great depths. The great rollers from the Antarctic break on the edge of the submerged plateau, and this is therefore a dangerous place for shipping. It is known as the Agulhas Bank, but really it is the edge of a sunken portion of the continent.

The Solid Globe.—Beneath the atmosphere, and in part beneath the hydrosphere or watery envelope, is the crust of the earth, or lithosphere, as distinguished from the central portion or centrosphere. We surmise that beneath the ocean the crust is precisely similar to what we find on dry land, because we know the latter has often been covered by the ocean in past times, and it follows logically, therefore, that the oceans must as often have been dry land. Our investigation into the nature of the crust must necessarily be confined to the continents and islands. The whole arrangement of land and sea has continually changed in the past history of the globe, and what we now find in the contours is an accident of the present time which cannot have existed in the past, nor will be continued in the future. The crook on the east of South America fits so nicely into the Gulf of Guinea, and the Americas on their eastern border generally show lines which correspond with the contours of the western shores of Europe and Africa, that it has been suggested that the two were once united, but were riven asunder when the moon was supposed to have been whirled away from where the Pacific now is. When we find that at least twice, in comparatively recent times, Africa was united with South America, the impossibility of this view becomes apparent.

A continent with all the irregularities of mountain, plain, and valley sinks beneath the level of the sea, and over the once dry land sediments are laid down, filling in all the hollows and reducing the surface to a more or less featureless plain. The junction between the old land surface and the newer sediments is called an *unconformity.* When the land rises again the action of rain and rivers again cuts into sediments, and produces once more mountains, plains, and valleys. In all continents the process has been repeated many times, each land period being marked by an unconformity between the older and newer sediments. The central idea of a continent is, therefore, a block of sediments compacted into rock which has been carved into the characteristic features by rivers and other agencies. The older the continent the more prominent the features, the more irregular the coast line, the more diverse the scenery. South Africa, land of straight seaboard and wide stretches of monotonously similar landscape, is by this criterion at once recognized as a new continent.

The rocks forming the land surfaces are mostly marine sediments. These are exposed on the flanks of mountains, and the once horizontal layers of sediment have been tilted by earth movements, so that by gathering information from various places we can estimate the total thickness of sediments. These may be set down at a maximum of 20 ml., but it must be understood that at no one place can we find a complete succession. Under the section dealing with earthquakes we shall learn that shocks may be recorded from distant places, and on studying these vibrations it is found that as long as the straight path between the origin of the earthquake and recording station does not pass deeper than 30 ml. in the earth's crust, which is spherical in shape, then the wave suffers no change; but directly the chord or straight path enters a portion of the earth deeper than 30 ml., there is an immediate change. From this evidence we judge, therefore, that the rocks we find at the surface of the earth continue downwards for 30 ml., but that, beneath, there is a centrosphere or nucleus of different material, probably meteoric iron and various iron-magnesium silicates, such as we find in meteorites. The evidence from radium is similar. If the radium content of the rocks is taken as 5 parts in a million million, then the heat of the earth's crust will be accounted for by such rocks forming an envelope 45 ml. thick, lying on a nucleus, cold and containing no radium. As we saw that the Rhodesia granite contained over 9 parts of radium in a million million parts of rock substance, the thickness of radium-containing rocks may well be under 45 ml. thick. We may take it as a fair estimate that the crust of the earth is 30 ml. thick. The deepest bore hole is only a little over 6000 ft. thick, and the deepest mine, Morro Velho gold mine, in Brazil, 4920 ft.,[1] so that bore holes and mines are quite insignificant in depth as compared with the whole crust. Even the crust is only a very thin layer overlying the centrosphere, for the distance of the centre of the earth from the surface is nearly 4000 ml.

The greatest elevation on the crust is Mount Everest, 29,000 ft. The greatest depression in the earth's crust is off the Ladrone or Marianna Islands, in the Pacific, 5269 fathoms, or 31,632 ft.; the Kermadec deep, near the islands of that name, north-east of New Zealand, is 31,000 ft. (5156 fathoms); so that the crust has irregularities in the surface of a little less than 6 ml. above the

[1] Arrangements are being made to continue the mine to 6500 ft.

mean sea level and just about 6 ml. below. The question arises: Is there any limit to these irregularities? I take the simplest case, that of the mountains. Can the earth's crust support an elevation greatly exceeding 6 ml.? An investigation into the crushing strengths of rocks proves that if a mountain stands over 6 ml. high, the weight of the mass will exceed that which the strength of the rocks will stand. The sea acts to a certain extent as a help to sustain the weight, but still, where there are great differences of elevation between the mountains on land and the bottom of the sea off shore, there is unstable equilibrium and movement takes place, evidenced by continuous earthquakes. Two such areas are very marked. In South America, south of the bend in the west coast, there is a very deep hollow in the ocean floor close inshore, in which soundings occur of 25,052 ft., and the Andes adjacent rise to a maximum of 23,100 ft. at Aconcagua, so that there is difference of level of over 48,000 ft. (9 ml.) within a short distance, and this area is celebrated for its earthquakes. Off the coast of Japan there is a great long hollow, following the eastern coast line, with depths exceeding 26,000 ft., while the mountains on the mainland reach a maximum in the sacred cone of Fujiyama, 12,390 ft. high, a total difference of level of about 38,500 ft. (7 ml.), and here again the land is shaken with incessant earthquakes. These instances show that the crust of the earth cannot be loaded beyond a certain limit without very marked effects being produced. In the continents of less-pronounced relief the same thing goes on, though by imperceptible stages, and continents are continually tending to sink; though this may be more than balanced by forces causing elevation.

The Rocks of the Earth's Crust.—There are three types of rocks composing the earth's crust: the sedimentary rocks, the metamorphic, and the igneous. The igneous rocks may be called the massive rocks, because they have hardened and crystallized in a continuous mass from a molten condition. The sedimentary rocks are called clastic or derivative, because they have been derived from other rocks which have been broken (*clao* in Greek means to break) by the processes of weathering. The metamorphic rocks are those which have undergone alteration by changes due to heat, pressure, and solvent water as they lie buried deep in the earth's crust. A metamorphic rock can therefore only appear on the surface by the removal of a great deal of rock that once covered it. Taking granite as the most typical igneous rock, we can show the relationship of the various types of rocks by the following diagrammatic scheme:—

IGNEOUS ROCK

Granite, consisting of	quartz,	composition	silica.
	felspar	,,	potash, lime, soda, alumina, silica.
	hornblende	,,	iron, magnesia, silica.

Splits up into—

SEDIMENTARY ROCKS

Sands, sandstones,	composition	silica from quartz.
Muds, shales,	,,	alumina, silica from felspar.
Limestone and dolomite,	,,	lime from the felspar; magnesia from the hornblende; carbon dioxide from the atmosphere.
Salt of the ocean	,,	potash and soda from the felspars.
Colouring matter	,,	iron from the hornblende.

METAMORPHIC ROCKS

Quartzite,	which is	altered	sandstone.
Slate,	,,	,,	shale.
Schist,	,,	,,	slate.
Marble,	,,	,,	limestone.
Gneiss	,,	,,	sandstones, shales, and limestones.

It is evident that nothing produced by the breaking down of the granite is lost; the materials are only scattered in the sedimentary rocks. If now, under extreme action of metamorphism, the water circulating in the pores of the rocks is allowed to carry substances from one rock to the other, the various substances may be reunited; the slates and schists will receive material from the quartzites and marbles and eventually the three types become welded into one common rock, which should be nearly the same in composition as the original granite. This is found actually to be the case, for at the end of the metamorphic series there is a class of rocks called gneisses, which are granites with banded structure containing just such quartz, felspar, and hornblende crystals as in the original granite, but laid one upon the other in layers. It is probable that there is a step further still, when the banded structure disappears and the gneiss does become a granite, and then the circle of change becomes complete.

Igneous rocks are supposed to have come up from the interior of the earth, molten with the original heat of the earth. In the old days heat was always connected with fire—*ignis*—therefore the molten rocks received the name igneous rocks. If the igneous rocks were once molten with heat it was not that due to the combustion of substances in the interior of the earth. There is, however, a large body of evidence which goes to show that they are rather solutions of substances in one another. If a disk of silver be laid on one of gold, and the two be kept under a very great pressure for a considerable time, the silver will be found to have worked into the gold, and vice versa; the two have dissolved each other, given pressure and time. In a similar manner rock substances

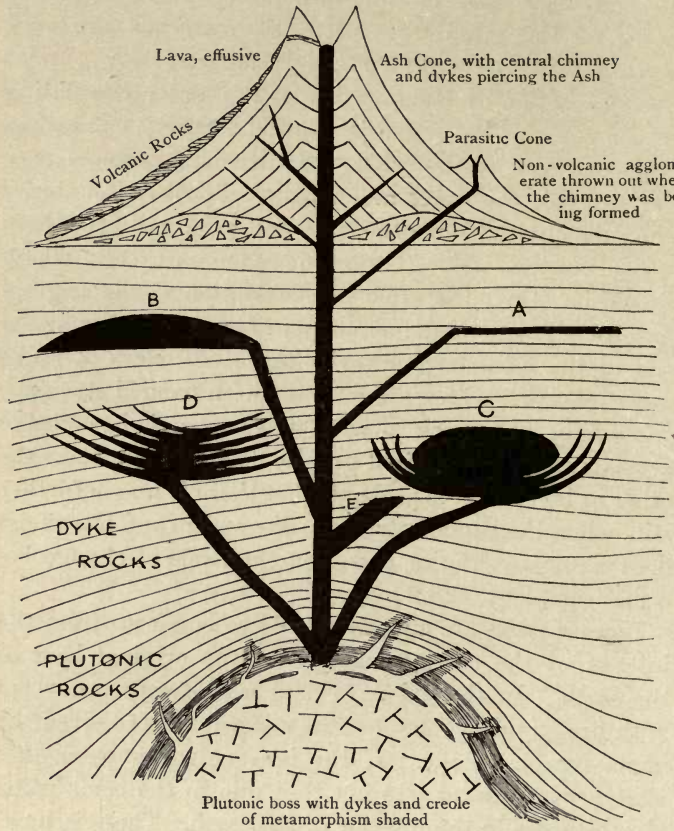


Fig. 9.—Diagram showing the Relationships of the Igneous Rocks

A, Dyke running into a sill. B, Laccolite, ordinary type. C, Bushveld type of laccolite. D, Cedar tree, or Karroo type of laccolite. E, Bysmalite (under C).

dissolve one another with or without the intervention of water; and though heat quickens the process it is not essential. A cup of tea consists of water on the one hand, and tea, sugar, and the substance of milk on the other. If we add enough sugar the water will practically disappear, and a sticky mass will be produced quite unlike the original tea concoction. In rocks, silica takes the place of water, and is called the acid; the other substances, representing the sugar, &c., are called the bases, and consist of alumina, iron, lime, potash, and soda. If there is an excess of silica, the rock crystallizes out as an acid rock; if there is an excess of the bases, then the rock is called a basic rock. If there are equal proportions of acid and bases, the rock is called an intermediate rock.

Another classification is based on the rapidity with which the rock has crystallized. In the depth of the earth the pressure is enormous, and the solution of silica and the bases crystallize out very slowly, so that the crystals are large. These have been called plutonic rocks, because they have formed in the nether regions, over which Pluto is supposed to reign. Offshoots from the main masses of the molten rock are intruded into the surrounding sediments as dykes, and these, being comparatively small bodies, crystallize fairly quickly, therefore the crystals are small. If the dyke finds an outlet to the surface a volcano will be formed, and from the chimney there will eventually issue a stream of molten rock or lava, which will be cooled so quickly that part or the whole of it may not have time to form crystals at all. The following is a diagrammatic scheme of the various rocks. Only those in heavy type will be described, as the characteristics of rocks generally is too big a subject to be considered here:

	Acid, with Quartz.	Intermediate.		Basic, with Iron Ores.	Ultra-basic.
		Potash Felspar.	Lime-soda Felspar.		
Plutonic (large crystals).	**Granite.**	Syenite.	Diorite.	Gabbro (norite).	Meteorites.
Dyke (small crystals).	**Quartz-porphyry**	Felspar-porphyry	Porphyrite.	**Dolerite** (diabase, altered dolerite).	—
Volcanic (with uncrystallized glass).	Rhyolite (obsidian and pumice).	Trachyte.	Andesite.	Basalt (melaphyre, altered basalt).	**Melilite Basalt,** (Kimberley blue ground, altered melilite basalt).

Granite consists essentially of quartz, which is easily distinguished in hand specimens as clear, wet-looking grains; the dull-white or pink grains, with smooth cleavage faces, are felspar; hornblende is dark-green or black, but more frequently in ordinary granite its place is taken by scales of black or white mica.

Quartz-porphyry consists of the same minerals, except that the quartz only, or the quartz and felspar only, have formed crystals, which lie in a fine-grained ground mass. When large crystals thus occur among much smaller crystals, they are said to be porphyritic crystals, and the rock is called a porphyry. Quartz-porphyry is a dyke rock, but passes, as all dykes do, into a volcanic rock, when the ground mass may have no crystals at all—that is to say, is glassy. If there are no crystals of any sort, not even porphyritic ones, then we have what is called volcanic glass or obsidian.

Dolerite is the corresponding basic dyke rock, and here the crystals are so small that they very rarely can be distinguished with the naked eye. The essential mineral is one of the bases, usually iron, in the form of magnetite or titaniferous magnetite, called ilmenite, the carbon of the Kimberley diamond diggers. Felspar occurs in tiny thin crystals, with the usual smooth cleavage faces, which sparkle and reflect the light as one turns the stone about in the sunlight. The black mineral is augite, which has the same composition as hornblende—namely, iron, magnesia, and silica.

Basalt is a lava of the same composition as dolerite; the crystals are usually very small, with occasionally porphyritic crystals of olivine. Very frequently it is full of blowholes, which may be empty, or they may be filled with chalcedony in concentric layers (banded agate),

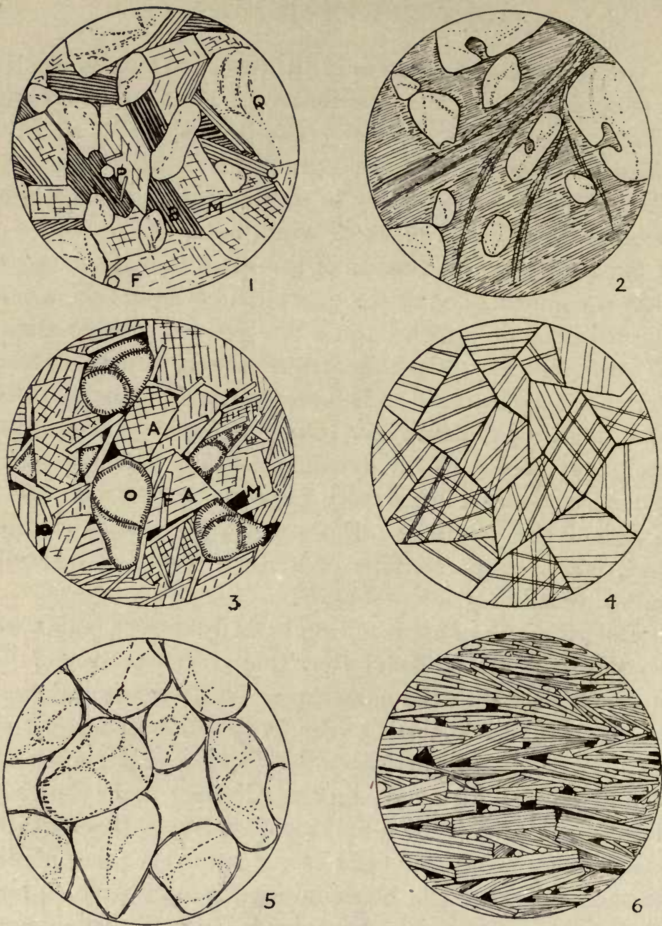


Fig. 10.—The Structures of Rocks as shown in their Sections

1, Granite, acid rock, all crystalline. Q, quartz = excess of acid; F, felspar; M, white mica; B, black mica; P, apatite, lime phosphate. 2, Quartz-porphyry. The quartz grains alone have had time to form; they have been corroded, and the matrix is volcanic glass, virtually all the substances that form the other crystals in granite melted up. 3, Dolerite, basic rock, all crystalline. M, Magnetite (black) iron ore = excess of base; O, olivine altering to serpentine; A, augite; F, felspar. 4, Marble composed of crystals of calcite; a sediment recrystallized. 5, A sandstone. Sand-grains water-worn, held together by a small amount of iron oxide, which coats the grains and colours the sandstone brown. Open spaces between the grains. 6, Chlorite schist. A recrystallized rock, scales of chlorite all in more or less parallel position, with grains of magnetite and quartz between.

or again with chlorite, calcite, or zeolites. The agates and other minerals are deposited by the water which oozes through the rock, and which in doing so absorbs certain substances; these substances are freed from solution as the water enters the cavities of the amygdules. Basalt with amygdules is called an amygdaloid.

Melilite basalt is a basalt without felspar. It consists of a titanium compound, ilmenite or perofskite, and olivine and augite, both of which consist of iron, magnesia, and silica. It is an ultra-basic lava, which occurs in the chimneys of many volcanoes, especially in South Africa. The olivine usually absorbs water and turns into a soft greenish or bluish material called serpentine, the principal constituent of blue ground. Altered ultra-basic lavas are the matrix of the diamond.

Sedimentary rocks are divided into sub-aqueous and sub-aerial rocks—that is to say, those that have been laid down under water or on dry land, like blown sand. Sub-aqueous rocks are again classed according to the nature of the water under which they are deposited; most of them are marine sediments with remains of marine shells and other animals contained in them. Estuarine deposits are those formed under brackish water, and contain mixtures of the remains of both fresh water and marine organisms. Freshwater deposits are those laid down under freshwater lakes or in rivers, and contain remains of animals and plants that live in fresh water. The limestones and salt deposits are sometimes separated from the sands and muds, which are called mechanical deposits, the limestones being classed as deposits due to organic precipitation, and the salt and gypsum beds are called deposits of chemical precipitation.

Sands or Arenaceous Sediments.—By far the larger proportion of sands are made up of grains of quartz, weathered out of granite, or derived from the disintegration of sandstones. The grains are small, and are therefore buoyed up when they are immersed in water, hence sands laid down under water are not completely rounded by grinding one against the other; they nearly always are covered with a certain amount of dirt lodged in the crevices of the grain, and usually become covered with a skin of colouring matter, red or yellow due to iron oxide, blue due to iron suphide, or green due to iron silicate, and the sandstones resulting from the consolidation of the sands is coloured accordingly.

Sand blown about in the desert or on the seashore is characterized by the complete rounding of the grains, whereas sand derived from the disintegration of rocks by frost, and occurring in glacier deposits, is characterized by the splintery and angular shapes of the grains.

Sand may be consolidated into sandstone merely by pressure, when the grains adhere by interlocking, or cement may be added by precipitation from water; and this cement, which may be compounds of iron, calcite, or silica, binds the grains into a firm rock, usually in such cases called *quartzite.* If the grains are sufficiently separated to allow the secondary silica to form crystals, these are formed round the grains, which appear in the centre of the crystals in their original forms, dirt and all. The glittering sandstones of the Molteno Beds are of this nature, the name being derived from the sparkling of the rock from the reflections from the innumerable facets of the crystals.

Ordinarily sands are laid down in successive horizontal layers or strata, but where there is a strong current the grains are heaped up in one place, and then, on the direction of the current changing, the top of the heap is washed away and the new deposit of sand is laid upon the older at a different angle. Current-bedded or false-bedded sandstones are characteristic of all the sandstone formations in South Africa, notably the Table Mountain Sandstone.

Where desert conditions prevail, the rocks may be split up by contraction and expansion due to variations of temperature, and the sand resulting contains fragments of all the minerals of the original rock quite unaltered. If the original rock is a granite, the sandstone containing the broken debris is called an *arkose*; otherwise such mixed sandstones are called *grits*.

In warm climates the shores abound in animal life, and dead shells are washed up in great abundance. These are dragged backwards and forwards by the tides until they are broken into fragments small enough to be carried by the wind. The dunes resulting from the accumulation of such sand will not be siliceous, but will be calcareous. The South African coast is surrounded by aeolian or windborne sand of this nature, and the fragments of shells being easily soluble in water containing a little carbon dioxide, the rainwater when it sinks into the dunes dissolves a certain amount, which is deposited when the water evaporates and cements the grains together; hence fairly firm limestones are produced which are used for building purposes. Quarries of this consolidated shell sand have been worked at Saldanha Bay and Bathurst; the Bluff at Durban consists of this material.

Muds, or argillaceous rocks, are made up of aluminium silicate or kaolin, derived from the disintegration of felspars. They are usually coloured grey, blue, or black with impurities, and weather to a clay.

Muds may be consolidated to shale, or into more compact forms called mudstones and clay slates. Slates are hardened considerably, and when they have been subjected to pressure often have planes of cleavage which allow them to be split into thin slabs. The cleavage develops quite independently of the original bedding planes, and is due to movement in the rock as the pressure squeezes it out laterally. Flagstones are slates with more massive structure. Phyllites are slates in which the planes of cleavage are covered with fine scales of mica, and are thus slates partially metamorphosed to schists.

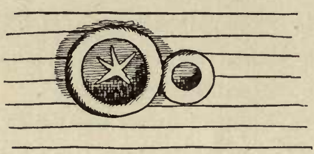


Fig. 11.—Spherical Limestone Septaria in Dwyka Shales. The balls have broken across level with the surface, and the interior has been removed by atmospheric agencies quicker than the harder rind. The cracks produced by the drying of the concretion, now filled with white calcite, are shown

Limestones vary from loosely compacted fragments of marine organisms, as in chalk, to the more dense varieties, as are found round Pretoria and in Bechuanaland in the Kaap plateau. The older limestones are mostly altered to dolomite by the replacement of a certain amount of lime by magnesia. They are usually coloured blue. On weathering, limestones and dolomites assume a brown, shaggy coat, like the skin of an elephant; hence the South African name for these weathered limestones—Olifant's Klip.

Septaria are patches of shale or sandstone cemented with lime, which has been deposited, after the rock has been hardened, by the percolation of water containing the lime in solution. The lime is usually precipitated originally round some organic substance, a fragment of bone or plant tissue, and the successive coats have been laid over the original nucleus concentrically. The bedding of the original rock passes through the septaria, and only when the rock weathers do the septaria become prominent, because of their superior hardness. The septaria usually contract after they have reached a certain size, and cracks form, which are subsequently filled in with pure calcite. The strange forms of these septaria in the Karroo shale and elsewhere has led to their being mistaken for fossil tortoises, &c.

Sometimes iron plays the part of cementing material, the order of events being the same as in the septaria. Then the structure is called a concretionary nodule. Red or yellow nodules of red or yellow ochre are common in the Witteberg rocks.

Coals are due to plant action. In many tropical forests, as in Sumatra, the trees grow, flourish, and die, and an accumulation of rotting vegetable matter forms about their bases. In northern climates moss forms accumulations of peat, which is similar in nature to the accumulations in the Sumatra forest; but the coal seams, showing throughout remnants of Stigmaria, or the roots of the great coal-period trees, Lepidodendron and Sigillaria, prove that most of the coals are formed from the higher plants. If such a mass of rotting vegetation becomes sealed up by mud and sand deposited by the sea which invades the land, then it will slowly alter to coal. In other places, as at the mouth of the Magdalene River, on the north of South America, vast quantities of trunks and branches of trees and other vegetable matter, torn from the forests by storms, are swept out to sea at every flood, and this material, becoming waterlogged, accumulates in the sediment at the bottom of the sea. Coal may thus be formed by *growth in place* or by *transportation*. In Europe and America most of the coal has formed by growth in place; beneath the coal seams there is found a fireclay, which is nothing but the ancient soil and often contains the roots and stems of the trees from which the coal was formed. In Cape Colony the coal has been formed by the transportation of material from afar, and the seams may lie on shale or sandstone and there may be a complete absence of the fireclay. The Transvaal coal has been formed by growth in place. Transportation coal is usually very shaly, the seams being made up of innumerable smaller seams, each separated by a parting of shale.

A vast time is necessary for woody tissue to turn into true coal, and hence the plants we find in coal, and which produced it, are of extinct kinds. In Europe and America the coal plants were called Lepidodendra, Sigillaria, and Calamites, whereas the coal in the southern hemisphere—Africa, India, &c.—was formed only partly by these, the most abundant plant represented as fossils in the coal formations there being ferns, called Glossopteris. If the vast time has not elapsed, then there is an intermediate stage between coal and wood, called *lignite*, which is a black or brown substance in which the woody structure can still be made out. Lignite deposits are found in the Cretaceous deposits of Oudtshoorn and elsewhere, but not in sufficient quantity to be commercially valuable. Lignite is worked along the Rhine, but it has to be treated by a special process and turned into briquettes before it can be used for fuel.

Metamorphic Rocks.—In quartzites and marbles the original sandstones and limestones have simply been hardened or recrystallized. By far the most common metamorphic rocks are the crystalline schists, which are shales or mud not only recrystallized but the substance of the mud changed to various crystals, quite different from those in the substance of the original rock. The term schist implies the fact that the rock is fissile or will split easily, and this character is due to the minerals of the schists being arranged with their flat faces all more or less parallel.

The commoner schists are chlorite or green schist, talc schist, black mica or biotite schist, and white mica or sericite schist.

Basic igneous rocks give hornblende schists which are rich green in colour.

Schists with felspar are called gneisses.

Meteorites are rocks that fall from the sky; they make themselves visible as they enter the earth's atmosphere by burning, and are known as shooting stars. By far the larger number burn entirely, and the ash thus formed falls as an impalpable powder as cosmic dust. The pure snowfields of the Arctic are covered with this fine dust. Some fall to the earth and are found to be of several kinds, varying from pure metallic ones to pure stony ones. The iron ones are very noticeable when they lie on the surface of the earth, and may be proved to be truly meteorites by polishing a surface and etching it with nitric acid, when an intricate system of crossing lines is seen to form, these being due to the crystalline nature of the nickel-iron alloy of which the meteorites are composed. The stony meteorites are mostly composed of ultra-basic rocks similar to the rocks in the Kimberley mines, but with characteristic rounded patches in them. Some meteorites consist partly of stone and partly of iron. It has been estimated that about a million meteorites fall on the earth in twenty-four hours, and in a year the weight of these amounts to some 20,000 tons.

SECTION II

DYNAMIC GEOLOGY

Weathering.—Passing now from the descriptive part of Geology to that part which deals with the natural forces in action on the earth, that is to say, to Dynamic Geology, the first and most important is weathering, or the action of heat, water, and air upon the rocks exposed on the surface.

The simplest case is where the action of heat alone is operative, as in the desert, and, as the desert is at our doors nearly everywhere in South Africa, this type of weathering may be taken here as at least of equal importance to the weathering under humid conditions, which is the only type usually represented in Europe.

Take, as an example, a mass of dolerite exposed on the top of a hill on the Karroo. The sun's rays cause the rock to become very hot during the day, and when the night comes all the heat absorbed during the day is radiated into space, and the rock cools. When material is heated it expands, and when it cools it contracts; therefore the mass of dolerite will expand and contract, just as much of it, at least, as has been warmed by the sun, for the inner portions remain at a more or less constant temperature. The outer portion, then, is moving over the inner, and after a time the rock will split at the junction. If the mass is exposed at the edge of the hill, as a krantz, the split portion will fall down in an avalanche of angular blocks. Each block now, at the foot of the hill, will be exposed to the same expansion and contraction as before; but as the corners expose a larger surface to the sun than the flat sides the heat will penetrate farther into the rock at the corners than at the sides. Consequently, when the expansion and contraction has gone on long enough to produce a crack, this will take on a curved surface, cutting off the angles of the block, and after the flakes have fallen away the angular block will have changed to a rounded one. The large rounded boulder now undergoes expansion and contraction as before; the spherical contour allows equal heating on all sides, and eventually the block will split into two or more portions. The angular portions of the boulder will now scale off, and smaller boulders will be produced, and so on. The process is repeated till the original angular block has broken down into small sand grains which can be caught up and carried by the wind, but the sand will consist of all the minerals of the original block quite unaltered. The sharp reports like cannon shots which are often heard in the desert at sundown are caused by the splitting of blocks as the heat absorbed during the day leaves them.

Suppose, now, that there is a little moisture. The fallen blocks become rounded, but in some cases they become soaked with water from dew or by fine rain. The water is absorbed in the pores of the rock, and, lying in the crevices, dissolves any of the substances in the rock which are readily soluble, the iron being usually the substance selected for solution in dolerite. When the sun comes out again the water is drawn to the surface of the boulder and evaporates, leaving behind a thin film of iron oxide. Gradually this process causes the boulder to become coated with a skin of black iron oxide, so that it comes to look like an iron cannon ball. In breaking open the boulder the central part will be found to be crumbly, because material has been removed from it to supply the outer coating. This weathering of the rocks from the centre and their hardening on the surface is very characteristic of deserts, and leads to peculiar effects in the shales; here the colouring matter is mostly iron, which becomes leached out and concentrated round the edges of the fragments, whereas the centres become bleached and pulverulent.

Weathering in humid regions is caused principally by the water soaking through the rocks; then, instead of the water being drawn to the surface by the heat of the sun, it is drained through the rock by constant accession of fresh moisture, so that the cementing material and the soluble constituents are leached out and the rock as a whole crumbles. Only those minerals which contain no soluble constituents remain unchanged; all those minerals which contain potash, lime, or soda, practically the felspars and white micas, and all those containing iron or magnesium, that is to say, the augites, hornblendes, and black micas, yield these substances to be dissolved. The water percolates through the minute crevices of the rock, and causes the rock to crumble away, leaving kaolin and talc, which are clayey substances, behind. Quartz, being practically insoluble at the surface of the earth, is always left behind as sand.

Weathering in snow-covered countries is again somewhat different. The alternations of temperature are here again excessive, and the rocks tend to crack; then the water melted from the snow during the warm hours of the day soaks in. But in the night-time this water freezes, and water has the peculiar property of expanding as it solidifies; therefore each little crevice is occupied by an expanded sheet of water, and the rock, just as a frozen waterpipe will do, bursts. The products of glacial weathering are usually angular blocks and splinters, and the soil resulting from the action is barren, as in the tundras of Northern Siberia.

Weathering by plants is either mechanical, when the roots penetrate into cracks and, as they enlarge, widen them and so split the rock effectually, or the weathering of the rock is brought about by the chemical action of the organic acids secreted by the roots. A familiar experiment to illustrate the latter is that of germinating a pea on a polished slab of marble. As the root grows it eats out a shallow groove on the polished surface, which is quite noticeable when the little plant has been removed. The corrosive action of lichens on rocks is another example. In ill-drained areas the organic acids produced by the roots of plants, grass, &c., accumulate and cause the soil to become sour. If limestone is put on this soil the acids attack it, and the soil becomes sweet as long as the supply of limestone lasts.

Weathering by animals is accomplished by worms, ants, moles, rabbits, meer-cats, and similar burrowing animals, which bring the rock from below the soil, where it is protected, to the surface, where it can undergo disintegration by heat and water. In Europe worms simply turn over the soil, as the constant moisture prevents the casts on the surface from drying; but in South Africa the casts are brought up from the wet soil and dry, pulverize, and are blown away, so that worms in South Africa are agents of erosion as well as agents of weathering.

Weathering that does not result in the crumbling of rocks, but, on the other hand, causes them to harden, is very common in South Africa. In shell sand the water penetrates the outer layers and dissolves a certain amount of calcareous matter, which is deposited when the water evaporates, so cementing the grains and producing a fairly hard rock. Ordinary quartz sands exposed on tops of hills become hardened in exactly the same way. Only, as it takes longer for water to dissolve silica, the action is slower; but for all that the silicification of sands on the tops of hills is extremely common throughout South Africa. Especially fine examples are exhibited in the plateau sands of Willowmore and Grahamstown. In England the same process went on in the Eocene Period, when the climate was warmer; all that is left now of these hardened sands are the Sarsen stones—isolated blocks of this material which have been used in times past by the Druids for building their temples, as at Stonehenge.

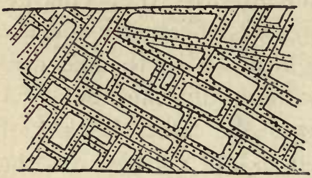


Fig. 12.—Snuff-box Shale, upper Dwyka shales; weathering from within. The cementing material of the rock becomes concentrated along the joints, leaving the interior of the blocks white and pulverulent

Somewhat similar to these silicified sands are the brilliant white freshwater quartzites that form such conspicuous objects in the Western Province, Malmesbury, &c. These are due to the silicification of sands in the marshes or vleys, and are probably due to the action of the minute siliceous plants (diatoms) which live in such places.

If the soil is sour, the acids elaborated by the plant roots collect. Now, organic acids have a powerful action on iron, and hence this material is dissolved out of the rocks on which the soil rests. As the water evaporates in the dry season the iron is deposited in the form of ironstone gravel, or concretionary limonite. This troublesome material forms under the soil, and is called in England *moor-bed-stone*, as it forms under the sour soil of the moors. In South Africa it has been given the name *Ou klip*. It is sometimes called *laterite*, but this only forms in tropical climates, and though its origin is similar it contains as much alumina as iron.

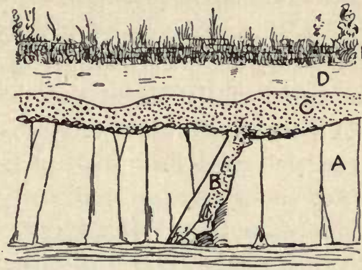


Fig. 13.—Section in Railway Cutting south of George Town, showing the formation of sour soil

A, Decomposed granite. B, Quartz vein. C, Ironstone gravel. D, Grey soil. E, Humus.

In Bechuanaland and in Natal, where there is an excess of lime in the soil, hard, platy limestone or calcareous tufa forms beneath in the same way as the ironstone gravel does. As it prevents the roots of plants from penetrating to the moister parts beneath, it is extremely troublesome in many cases. It is called in India *kankar*. All these substances, kankar, laterite, ironstone gravel, freshwater quartzite, silicified sand, are instances of rocks *being formed* by weathering.

Erosion is the wearing away of rocks by the agency of wind, water, or ice; the tools of erosion are the sand grains, gravel, or boulders carried by these agents. In wind erosion the sand is carried with considerable force, and impinges on the outstanding rocks, and the softer parts are in time worn away. In granite, for instance, the felspars, being softer than the quartz, under the influence of wind erosion will wear away, and the granite will become pitted. In the deserts this kind of erosion is intense.

River erosion is accomplished by the sand and gravel dragged along by the current: the action is that of a continuous application of sandpaper to the sides and floor of the valley. Marine erosion is similarly accomplished by the waves dragging backwards and forwards the rubble fallen from the cliffs.

A peculiar form of erosion occurs when a stone becomes loosened in a rock in the river bed: the current is not enough to sweep it away, and the stone therefore oscillates and gradually grinds its hollow larger. Other stones may be dropped into the hole, and the more there are the more vigorous does the churning and boring action become, until quite deep cylindrical holes result. These are called pot holes, and are sometimes several feet deep. They must be distinguished from the swallow holes, due to solution of limestone along crevices.

Ice erosion is accomplished by the boulders that are frozen in the bottom and sides of glaciers, which, as they move downhill, press against the bottom and sides of the valley like chisels held in a vice. But as the ice melts readily under pressure, the boulders continually shift their position and expose new surfaces to the floor over which they are moving. Grooves are thus cut by these boulders in the floor; they are not continuous, but peter out after a short distance, and also show peculiar chatter marks, like when a cold chisel is held loosely in the hand and made to move over a surface of metal. Where the floor consists of stratified rocks the moving ice often strips off slabs, which then go to swell the mass of morainic material. The erosive action of glaciers is small, and is quite overshadowed by the weathering due to the ice lying in contact with the rocks; the rocks become shattered by being kept wet constantly, and the moisture alternately being thawed and frozen in the crevices.

There is another form of erosion common in South Africa, due to the sliding of gravel down the hills. On the top of the slopes the bare rock is exposed, and fragments are continually being broken off by expansion and contraction due to alternating heat and cold. The blocks fall on the soil and gradually sink through it; for when soil becomes wet it swells, and does so round the blocks, because where the blocks rest the rain cannot penetrate. Eventually, a short way from the crest of the hill, the soil will be found to be underlain by a continuous layer of angular blocks, and as the soil moves downwards at every rain it carries with it the gravel beneath, so that the soil acts much as a glacier does, and the gravel beneath represents the ground moraine. Sub-soil gravel on a hillside will perform all the peculiar actions which ground moraines will do: it will ride over obstructions, producing roches moutonnées, pluck off slabs, will fill in depressions, and finally at the bottom, where the river washes away the soil, will leave a mass of gravel very similar to a terminal moraine. In very humid regions, as on the flanks of the snow-capped mountains and on the fringe of the Arctic and Antarctic, such as in the islands of Kerguelen and the Falkland Islands, soil-flow is very marked; it has been called *soli-fluction.*

Denudation.—These two processes, weathering and

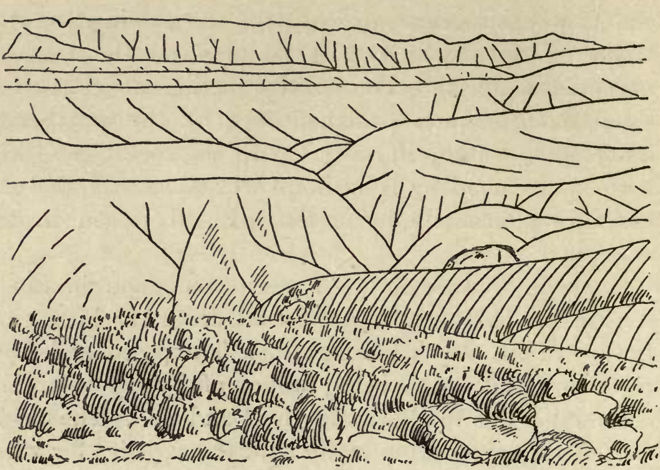


Fig. 14.—"Ruggens"; peneplain eroded in soft Bokkeveld slates and cut into by deep gorges. Range of Table Mountain sandstone hills in the distance. Paarde Kop, Knysna

erosion, are together called denudation. Land is denuded all over, but more vigorously in the river valleys.

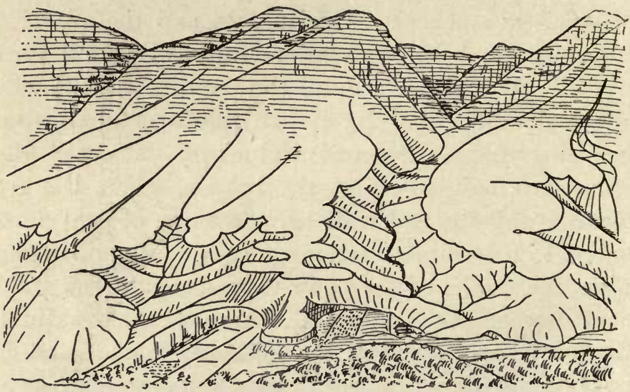


Fig. 15.—A Dissected Peneplain. The tributaries of the main stream are still separated by flat divides, Kammanassie River, Oudtshoorn

It is, however, evident that if the base-level of the rivers remains the same for any great length of time, the whole continent will be denuded down to sea level. Such a plain, base-levelled by river action, is called "an almost plain", or *peneplain*. If marine erosion has cut a shelf

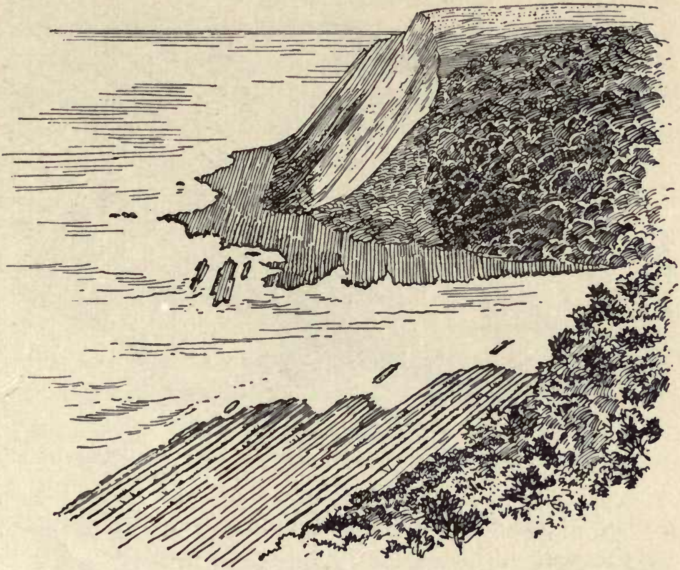


Fig. 16.—Coastal Shelves or Plains of Marine Denudation; one at sea-level uncovered at low tide, and one 600 feet above

at the foot of the cliffs this is called a *plain of marine denudation*; it is distinguished from a peneplain by the presence upon it of sea-shells and the remains of other marine organisms. *Raised beaches,* resting on plains of marine denudation, are found all along the south-eastern shores of South Africa up to 1300 ft. above sea-level. If the average level of South Africa be taken at 3000 ft., and it requires 3000 years to remove to the sea material which if spread over the surface would cover it 1 ft. deep, then in nine million years South Africa would be awash. There are forces which counterbalance this degradation of the continents, in that they cause the elevation of land surfaces, nevertheless in the course of

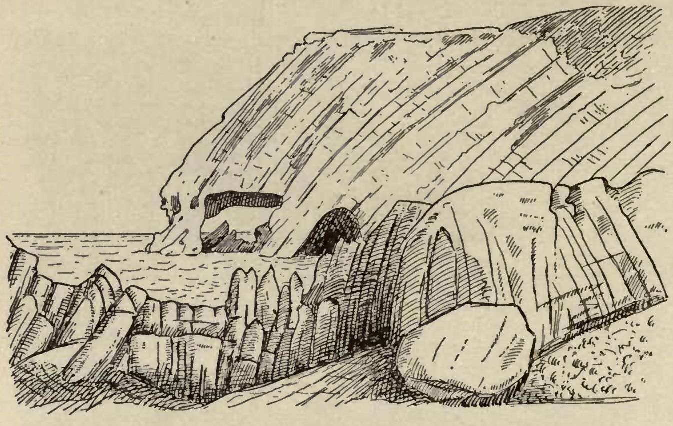


Fig. 17.—Arch and Cave along Knysna Coast near Seal Point. Height of cliffs, 600 feet. Plain of marine denudation in course of formation. High water

geological time the land has been covered repeatedly by the sea.

Mountains of Circumdenudation. — Weathering and erosion go on most vigorously along the river courses, and hence it frequently happens that blocks of land between two river systems remain comparatively free from attack, while the surrounding country is cut away. These blocks stand out as mountains of circumdenudation. The Karroo kopjes are the type of this kind of mountain. Their sides are said to be scarped or to form an escarpment. If the rock is sufficiently hard to turn aside the rivers, as in the case of a granite boss intruded into soft slate, then another type of mountain of circumdenudation results.

Underground Water.—In limestone regions, water sinking through the cracks in the rocks dissolves a certain amount in its passage, and in time the crack is enlarged. On the surface these enlarged cracks are trumpet-shaped, and are called swallow holes. They may be filled with water, when they form peculiar circular pools; or they may be choked up with soil, which is markedly more moist than the surrounding soil. The underground cracks, when enlarged, become subterranean rivers, which drain off all available moisture, and the surface becomes arid and waterless. This type of country is called *karst,* and is typically developed on the east of the Adriatic, but is also well exhibited in the Kaap plateau in Bechuanaland. The rivers issue on the low ground, and deposit quantities of calcareous tufa or travertine, which represents the material dissolved in the passage through the limestone. Caves and subterranean lakes are similarly formed, the most famous examples of which are the Cango caves of Oudtshoorn.

All rocks are penetrated by water, and the term *living rock* refers to a rock still in its natural position and from which this water has not been driven off. In the lower depths of the earth's crust this water has an important rôle in ore formation. But besides this water there is also underground water that can be tapped with bore holes. Mostly this is contained in cracks due to the long heating and cooling which results from the change from summer to winter. In the Karroo these seasonal changes of temperature can be felt down to about 60 to 80 ft.; below, the rock is uncracked, therefore if we bore through the cracked portion of the surface rocks down to the uncracked portion we shall find there all the water that has soaked in from the rains. In Rhodesia and Bechuanaland the depth of this level is from 300 to 350 ft. The water in the cracked portion of the rocks is always moving from the higher to the lower levels, and care must be exercised, in locating a site for boring, that there is no outlet by which the water can be drained away. In well-watered countries the cracked portion of the rocks is always well supplied with water, and there is no definite water table or underground surface of the water, which lies above the impervious zone, and which rises and falls according to the annual rainfall. In South Africa, however, the rainfall is so small that the level for striking water practically coincides with the zone of division between the cracked and uncracked rocks.

There are exceedingly few pervious rocks in South Africa, and these mostly confined to the Cretaceous and Recent rocks of the coast; the chances for artesian water in South Africa, therefore, are few, except in these formations. There are deep-seated sources of water, however, which depend firstly on the rocks below the zone of surface-splitting being fissured by earth movements, and in these deep crevices water actively circulates. The Uitenhage spring comes from such a structural fissure. Secondly, the dolerite dykes form walls which bring up the waters of these deep crevices to the surface, as at De Aar and Beaufort West.

Volcanoes.—The most terrifying of geological activities is that of volcanoes; the earth is riven, and up the crevice boulders, ash, and eventually molten rock are vomited. The cause of volcanic action is undergoing revision. Geologists were afraid to peep into a volcanic crater in action until Dr. Brun went and did so, and the results of his investigations have upset the theorizing of previous geologists who observed volcanoes from afar. Formerly it was supposed that water played an important rôle in volcanic activity; water, in contact with rock, molten and at a very high temperature, would be in an explosive condition, and water, therefore, was held to be the agent which shot the rocks and ash upwards. Brun, however, has pumped into his receiving vessels samples of the gases given off from volcanoes in their explosive condition, actually standing on the crest of the crater and dangling his receiving pipes into the uprushing vapours, and he finds that the gases given off are totally devoid of water. The gases actually present are carbon dioxide, carbon monoxide, marsh gas, nitrogen, and hydrogen, sometimes chlorine, and also a large quantity of ammonium chloride (sal-ammoniac) as a fine solid powder, which ascends and spreads out over the volcano as a mushroom-shaped cloud. Sometimes the cloud does not ascend, but, like a dense cloud of smoke, rolls down the hillside, and withers up all life which comes into contact with the intensely hot fumes. In 1902 the whole population of the town of San Pierre, in Martinique, was annihilated by the burning cloud (*nuée ardente*) which was rolled down from the volcano Mont Pelé. At other times the crater becomes full of water and forms a crater lake; on the Peak of Tristan da Cunha, which is a volcanic mountain, there is such a crater lake. If, now, the volcano becomes active, the ash is shot through the water, and the whole rolls down the side of the mountain as a hot liquid mud, engulfing animals and trees in its rush. Volcanic mud-rushes of this kind are common in Java, and we have evidence of their having been very frequent when the volcanoes of the Drakensberg were active, for we find a volcanic sand, the Cave Sandstone, with all the characters of such a mud-rush, and embedded in it are the giant reptiles (Dinosaurs) which browsed once on the rich grass on the flanks of the volcanoes.

Mud volcanoes, such as occur in the Bay of Bengal and throw up islands of hot mud, are due to the combustion of oil or oil gas in the interior of the earth. As Brun finds marsh gas, which is oil gas, in all true volcanic explosions, the essential difference between mud volcanoes and true volcanoes, which was formerly insisted upon, is not now so great.

The action of a volcano may be divided into several stages.

1st Stage. Clearing the Throat.—The gas liberated from molten rock, raised to the explosion point by some source of heat within the earth, tends to burst outwards, and should a crack lead to the surface the gas tears up it, drilling a cylindrical chimney. The material thrown out may be fine dust torn from the sides, when the rocks traversed are solid granite; or, if the rocks admit of "plucking", as in the case of sedimentary beds especially, blocks are hurled forth. The fine powdered rock or the boulders, angular as they have been torn off, or rounded by their grinding against each other, are strewn round the orifice as non-volcanic ash, breccia, or agglomerate.

2nd Stage. The Emission of Ash.—Into the chimney so formed the lava rushes; but the gases imprisoned in it expand, now there is free space for them to do so, and the liquid rock is blown into the finest powder, which is cast out at the surface with terrific violence. Some of it is so fine that it floats for weeks and months in the atmosphere; but the coarser particles fall to the ground in the neighbourhood, according as the wind carries them, covering wide areas with the fine white powder. The still coarser particles fall round the orifice, and gradually build up an ash cone, the funnel-shaped opening of which is called the crater. As the violence becomes less, larger lumps of liquid lava are thrown out, and, after hurtling through the air, fall, more or less cooled, as lapilli or bombs. If there is much gas left in the molten rock when it is thus thrown as lumps in the air, it still expands and blows the liquid rock into a vesicular mass called pumice. Finally, lumps may be belched out which may solidify as solid volcanic glass, that is, molten rock that has cooled so quickly that it has not had time to crystallize.

3rd Stage. Lava Flows.—The head of the column of liquid lava having been blown off, the rest of the lava rises quietly and occupies the chimney. Hydrostatic pressure is at work, and the cone, composed of loose, unconsolidated ash, becomes riddled with dykes of lava where crevices allow the molten rock to enter. Eventually the lava rises so high that a part of the crater breaks away, and a lava stream issues forth and flows down the side of the hill. Subsidiary or parasitic cones may arise by the dykes finding an exit on the side of the main cone.

4th Stage. Solfataric Stage.—The lava has come to rest; no more gas is available for driving it forth, and consequently the lava column solidifies in the throat of the valcano. The gases, however, are still being given off, and work their way along crevices in the shattered rocks round the chimney, until they escape at the surface, and fumaroles or fume jets of carbon dioxide and so forth are produced. Solfataras are jets of sulphurous vapours formed in the same way. Hydrochloric and boric acids are also sometimes given off, as in Nea Kameni, near Micra, in the Grecian Archepalago, and in the lagoons of Tuscany, respectively.

5th Stage. Geyser Stage.—This is the last expiring manifestation of the volcano, when superficial water wins its way to the still hot centre of the volcano, and returns back to the surface impelled by the steam generated at the contact. The steam accumulates slowly, and every now and again drives out the water in front of it with considerable violence; then the geyser spouts. When all the steam is expended the water falls back to wait for another accumulation of steam pressure to come up again. As hot water under pressure is a strong solvent of silica, the water in geysers holds a large quantity of this substance in solution. When it issues on the surface, temperature and pressure are reduced, and the silica, becoming insoluble, is deposited as siliceous sinter round the surface of the geyser. Beautiful pools and terraces are formed in this way; those of Rotamahana, in the northern part of New Zealand, were one of the seven wonders of the world, but they were blown into the air in the renewed activity of the volcano Tarawera, and the sinter terraces of the Yellowstone Park are the best example we now have of them.

A volcano does not necessarily go through all these stages; activity may stop at any one stage, and the chimney may be blocked with debris of non-volcanic material of the first stage, fine non-volcanic dust, or coarser agglomerate, as in many cases in the Drakensberg. It may be filled with volcanic ash of the second stage, or it may be filled with a plug of lava of the third stage. The Kimberley diamond pipes are of the last kind, but here the lava plug has been altered by the percolation of superficial water of the fifth stage,

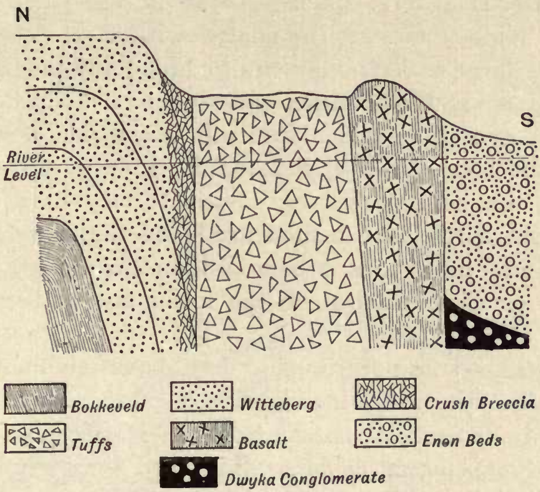


Fig. 18.—Section through a Volcanic Neck, the ash cone of which has been swept away by denudation. Mimosa, near Port Elizabeth

which has changed the rock into a serpentine, expanding it in the process and forcing it to move upwards in the vent. At the same time the carbon gases of the fourth stage have been working through the mass, and from them are derived the diamonds by a process of deposition which is similar to that which is responsible for the formation of many ordinary minerals occurring in less extraordinary rocks, for instance, andalusite from granite. Volcanoes do not always issue from single cracks;

indeed most volcanoes lie along fissures which have been enlarged to volcanic vents at certain points. The fissure may gape sufficiently to let the lava stream come pouring out with but little preparatory explosions; then only a few small spitting cones are formed, and the whole country for miles round is flooded with the issuing lava stream. If several fissures occur in the same area, whole regions may be inundated with lava. Such an area, as large as France, occurs in Idaho and neighbouring states, and the Mawi plateau, in British Central Africa, is of the same nature. It is possible, however, that the lava of these plateaux is of extra terrestrial origin, that is, a very large meteorite may have fallen upon the earth, have melted itself and the rocks it fell upon, and have thus produced these lava seas. The Maria or dark patches of the moon are similar lava seas.

Caldera.—Volcanoes, again, may have chimneys so large that the usual manifestations of those with narrow throats are not represented. These volcanoes have, instead of craters, caldera, which are simply rounded holes in the earth's crust, up to 2 ml. in diameter, up which the lava comes, but does not overflow, forming a gigantic lava lake. When the molten rock cools, the lava solidifies as a crust. The great Kilauea, in the Hawaiian Islands, is the most famous of these caldera; it rises 30,000 ft. from the sea floor, and Brun has recently observed in an eruption that the surplus lava flows down subterranean channels, and must find exit beneath the sea. Similar caldera exist in the South Sea Islands, and extinct volcanoes of this type are found on the northern flanks of the Alps, at Hegau and the Ries. Such large orifices are not probably filled entirely with lava; from comparison with volcanoes of like nature in different parts of the world it is probable that they

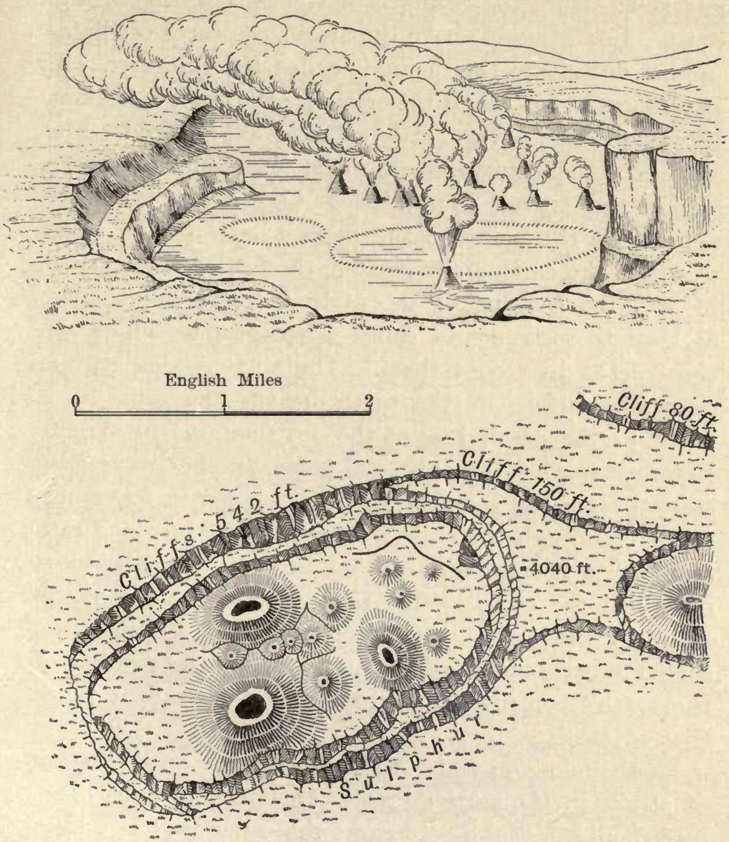


Fig. 19.—The Non-explosive Type of Volcano. The cauldron lake of lava (caldera) of Kilauea in the Hawaiian Islands

are occasioned by a plug of the earth's crust sinking, and round the edge lava comes welling up. The cauldron subsidence of Glencoe, in Scotland, is of this type.

Earthquakes.—When the explosion of gas within the earth's interior occurs, and no vent for the escape of gas is at hand, the result is a violent heaving of the crust. Immediately above the origin, the earth oscillates up and down, and this point is called the *epicentre.* In lessening amount round the epicentre the crust is shaken, till at a distance very little effect is experienced. The wave proceeds outwards, however, in ever-broadening circles, and travels round the globe. When the wave approaches the point on the opposite side of the globe to where the earthquake started, the circles will narrow in, and the shaking of the earth becomes appreciable, at least to instruments, called seismographs, which are constructed to record them. The wave which travels over the surface of the earth heaves the crust as a wave in the ocean heaves the ice floes in the Arctic. Before it reaches the antipodal point, another wave that started from the same origin has reached it, travelling directly through the earth's centre. We know the rate at which waves are transmitted through the substances of which the earth's crust is made, and we know the rate at which the wave is transmitted through the earth's centre, therefore we can calculate the rigidity of the earth's centrosphere, which works out about twice that of steel.

Earthquakes may also be caused by the accumulation of strain in the earth's crust. One part may be overloaded, and is tending to sink; the other part is underloaded, and is tending to rise. At last a time comes when the earth cracks between the two portions, a fault is produced, and coincidently the earth is shaken; but in this case the epicentre will be a straight line. The great San Francisco earthquake was of this type, and the terrifying effect of this has led to too much concentration on this particular kind. The destructiveness of an earthquake depends on the amplitude and period of the wave. The amplitude is the actual throw of the ground at the particular place: a throw of 1 in. will destroy a town if the period be rapid. The period is the time required for a point in the ground to rise and fall back to the same place. Periods of two or three seconds are disastrous with even small throws, whereas periods of half a minute to a minute are not serious. The shake spreads from the origin in concentric shells, and the destruction of houses in the epicentral and adjoining areas is marked by cracks parallel to the surface of the sphere at that place; that is to say, going north from the epicentre the cracks will incline to the north at greater and greater angles as the distance increases, and going south, east, or west they will incline south, east, or west in the same way. By constructing lines at right angles to the cracks of the buildings, therefore, they will be found to converge to a point which is the origin or focus.

Secular Upheaval and Subsidence.—When in nine million years the whole of the mass of South Africa standing above the sea has been removed and transported to the sea adjacent, the crust of the earth will have been lightened by many millions of millions of tons, and the sea floor weighted by the same amount, less the weight of the substances that have gone into solution. Now we saw that when the force of gravity was lessened on one side of the earth by the sun and moon pulling together on the other side, the water of the ocean bunched itself into a tidal bulge. The sun and the moon have only a slight effect on the rocks of the earth, but the earth itself controls the rocks on the surface by gravitational pull. When the weight of the rocks is removed from a continental area, there is less material to pull in towards the centre, and the earth's crust consequently bulges; whereas, when the sea floor is weighed with sediments, it sinks, for the earth, though solid, allows long-sustained forces to operate on its form as if it were a liquid, while to sudden jars, like that of earthquakes, it is perfectly rigid. The relief from unloading and overloading is usually obtained by fits and starts, not continuously, so that there is a long period of quiescence, then the strain becomes too great and the earth's crust gives along a line of fault. Not only so, but it usually happens that when movement does occur of this nature, the segment of the earth springs up more than equilibrium demands, and hence there is an adjustment afterwards, when the portion elevated sinks a certain amount. Sinking and rising go on continuously, now one predominating, now the other. South Africa at the present time is on the rise, but the movement is one following a period of subsidence. Resting stages in the progress of the elevation of land masses are shown by the rivers cutting down to base level, consequently South Africa should show peneplains at various elevations, and these are everywhere extraordinarily well developed. The first great peneplain—perhaps, rather, in this case, an original plain of deposition in the Karroo grading into a peneplain on the north—was at what is now 6000 ft. above sea level. The Witwatersrand, the Central Karroo hills, Nieuweveld, Cambdeboo, Winterberg, &c., and the coastal mountains, the Zwartberg, Cederberg, Langberg, Outeniquas, Cockscomb, &c., all rise to this level. Cut into this great plain are all the valleys of the subcontinent, which have been carved by the rivers as the land gradually rose to 6600 ft. The rise was not continuous, however; after the first 2000-ft. elevation, the land stopped rising and a great peneplain was eroded at this level, now 4000 ft. above sea level. The next resting stage was at 2500 ft. above present sea level, and succeeding levels are at 1500 ft., 600 ft., sea level, and 600 feet below sea level.

The only place where these have been studied in detail is in Cape Colony. The 4000-ft. peneplain is still found in the mountainous country between Uniondale, Oudtshoorn, and Prince Albert. Remains of the gravel-capped plains at the last-named place show that the 4000-ft. peneplain probably extended to the escarpment of the Nieuweveld Mountains, for the isolated hills of the Karroo between rise to this level. The 4000-ft. peneplain was submerged, and covered with Cretaceous deposits which were subsequently let down into fault pits. It then rose again to the old level and all the loose Cretaceous deposits, except in a few isolated cases, were swept away, and the Cretaceous deposits, themselves lying in the fault pits, were cut off on top to the 4000-ft. level. There are consequently two peneplains at 4000 ft. above present sea level, which are respectively pre-Cretaceous and post-Cretaceous. The 2500-ft. level is only markedly shown in the native territories east of the Kei River, but remains of it are seen in the hills about Grahamstown for instance, and farther north in the Queenstown Division. In the Transkei the great post-cart road to Natal is carried on this level, descending every now and again the steep gorges of the rivers that have cut into it. Most of the gravel and sand of the original peneplain have been removed, but in isolated cases, as at

Kentani Hill, there are little caps of this material still in place.

The 1500-ft. level is developed near East London and at Sandflats on the Midland line, where marine deposits occur upon it belonging to the uppermost Cretaceous age; elsewhere the plain has been denuded of the deposits and simply exhibits a flat shelf. The marine deposits show that where they occur the plain is a terrace of marine erosion and that the sea beat against the cliffs, now inland, which were topped by the 2500-ft. level.

The 600-ft. peneplain is the general level of the coastal flats right from Caledon, through Swellendam, George, Knysna, Humansdorp, and far to the east. It is covered with great deposits of surface quartzite and ironstone gravel, showing that a part of it, at least, was river-cut, though the seaward end is no doubt due to marine erosion.

Sea-level terraces are well developed off the Bredasdorp and Riversdale coasts, and eastwards along the coast at intervals, as at Port Elizabeth, the Kowie, on the Natal border, and in Zululand. All these terraces swarm with marine organisms, mostly lime-secreting, such as shell fish, Polyzoa, Coralline seaweeds, &c., and regular reefs of newly formed limestone are being constructed which are of the same nature as the coral reefs which begin to make their appearance on the east coast north of Beira, only here the lime-secreting organisms are more entirely coral animals. Such reefs have been called stone reefs in contradistinction to coral reefs; they often contain beach boulders and shore sand.

The −600-ft. terrace, or the shelf submerged 600 ft., is the Agulhas plateau, which prolongs the truncated contour of South Africa some 90 ml. southwards to a

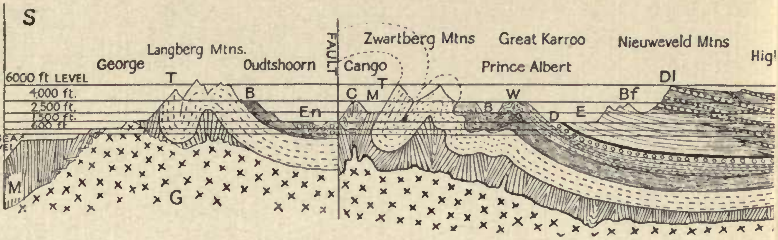
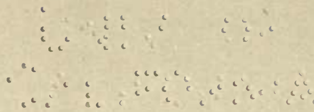
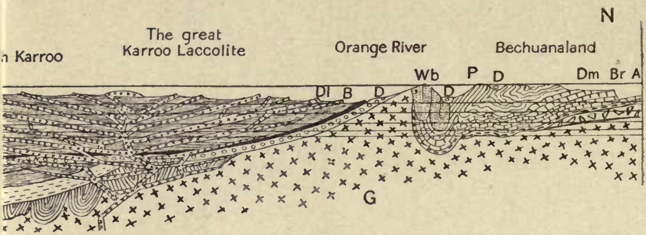


Fig. 20.—Generalized Section through Cape C

G, Granite, intrusive. M, Malmesbury beds. C, Cango conglomerate. T, Table Mou conglomerate. E, Ecca beds. B, Beaufort beds. Dl, Dolerite forming the cedar-tree l north. Wb, Waterberg. P, Pretoria beds. Dm, Dolomite. Bf, Black reef. A, Pn

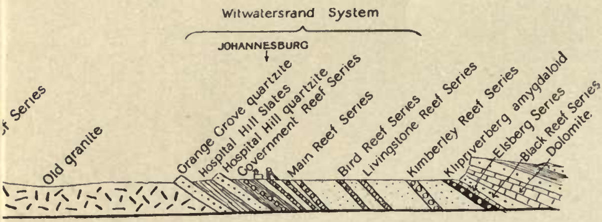
Fig. 52.—Diagrammatic Section through Johannesburg and Pretoria, showing





olony from North to South

intain sandstone. B, Bokkeveld beds. W, Witteberg beds. D, Dwyka accolite of the Karroo. En, Enon conglomerate. Pal-Afric beds of the il amygdaloid.



the great Laccolite with the Selvage of Basic Rocks (norites) symmetrical point. Its farthermost edge is 90 fathoms, and beyond that is very deep water. Boulders have been dredged from off it 40 ml. from land, consequently this shelf was once dry land. Further evidence of this sinking is furnished by the rivers, such as the Buffalo at East London, where the rock channel lies 122 ft. below sea level, the shallow channel now existing being due to the filling in of the rock channel with sand.

All these levels mentioned are major stages; each has an indefinite number of minor stages. Looking from the Cockscomb Mountain over the country about Port Elizabeth one sees the land cut into a succession of steps down from the 4000-ft. level. In the case of the 1500-ft. level in this area the marine deposits (Alexandria Beds) occur on every level with similar shells down to that forming on the present shore, showing that the land rose by stages of 50 to 100 ft. at a time, then rested, allowing a shelf to be cut, and then rose again, and so on. The steps in such a case belong to one and the same plain, like the steps of a staircase belonging to one flight of stairs, and such a stepped plain is called a *klimakotopedion*, which is simply the English term translated into Greek. The submerged Agulhas plateau is of the same nature, as has been shown by soundings. Inland, the major stages are similarly stepped, owing, in this case, to rivers being checked at various levels. Thus at Grahamstown the high hills around belong to the 2500-ft. level, the flats about the town are some 250 ft. lower, and the town itself is in a **V**-shaped river valley not old enough to have been levelled. The levels run throughout South Africa with extraordinary constancy. Local variations occur, causing any particular level to be above or below the normal. This is due to the presence or absence of the river or marine deposits once universally spread over it, but sometimes it appears that the land has tilted since the cutting of the level. The main impression, however, is that South Africa has risen as an iceberg would when the ice melts.

SECTION III

TECTONIC GEOLOGY

Tectonic Geology is concerned with structures exhibited in the earth's crust.

Stratification.—When a river comes down in flood it pours out over the sea floor an immense amount of sand and mud, which eventually subsides and forms a more or less horizontal stratum or bed of sediment. The surface of this deposit will be smoothed by the currents in the water, so that, when the next flood carries fresh sand and mud over the previous deposit, the two will be separated by a plane of division marked by the smoothed surface of the underlying one. This plane of division is called a bedding plane. When the sand and mud are consolidated into sandstone and shale, and elevated above the sea, the bedding plane will be clearly shown as a division. All sedimentary rocks are arranged in strata which were deposited intermittently, each stratum being marked above and below by a bedding plane; hence sedimentary beds are stratified rocks. It is evident that the supply of sediment is limited, therefore the stratum of deposit will thin out on the edges, and consequently the strata of rocks are always more or less lenticular, that is, they thin out at the edges.

If the currents in the water are violent, the sand is heaped up in one place, and the layers or strata are steeply inclined. When the direction of the current changes, owing to the tide or wind, the tops of the mounds will be washed away, and new material will be laid down on the side of the mound opposite to that on which it was previously deposited. This action is called *contemporaneous erosion and deposit*, and the irregular stratification is called false or current bedding. Wind-blown sand is always markedly false-bedded.

Unconformity.—The old rock surface of the sea floor on which the sediment is deposited must have been cut when it was exposed as dry land, as below low tide no erosion takes place. The submerged land surface is then said to be covered unconformably by the newer sediment, and the plane of division between the two is called an *unconformity*. An unconformity always implies a land surface; so that, if in the side of a hill one set of beds is seen to lie unconformably upon another, we know for a certainty that the two are widely separated in time, for the lower sediments were laid down in the sea; compacted into rock; elevated into dry land; cut into peak, valley, and plain; were again submerged, before the overlying sediments were deposited upon them. The most conspicuous example of an unconformity is the sandstone forming the top of Table Mountain at Cape Town, resting on the eroded surface of the granite and clay-slate below.

Joints.—When the sediments have accumulated to any great depth, the sea floor sinking continuously, as explained under the heading "secular upheaval and subsidence", the lower portions become compacted by the weight of the superincumbent material and turned into rock—the more the load the greater the compactness of the rock. When the sediments rise and form dry land, the overlying beds become washed away and cut away by weathering and erosion, so that successively older and older beds become laid bare on the surface of the earth. When the pressure under which they have lain for ages is thus relieved, the rocks expand, and two systems of vertical cracks develop at right angles to one another—rarely at other angles—due to the movement consequent on the relief of pressure. These cracks are called joints, and can be seen in any quarry, for they allow square blocks to be split off, while the bedding planes give horizontal planes of cleavage.

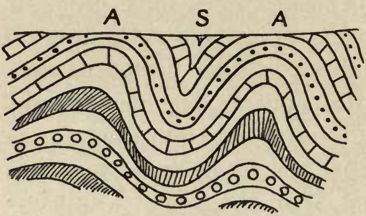


Fig. 21.—Synclines S and Anticlines A, A

Folding. — In most cases where there is an elevation of the land, disturbances occur which occasion horizontal pressure; the simplest case is where a mass of igneous rock like the dolerite of the Karroo is intruded into, and pushes outwards, the sedimentary rocks it invades. If the horizontal thrust is brought up against a buffer, such as a core of granite anchored to the substructure of the crust, then the beds are slowly bent. The movement is brought about by the solution of the grains in position of pressure, and deposition of the material dissolved in positions of less pressure, so that a massive bed of hard sandstone may be twisted into bends and crinkles while it remains solid all the while. A fold which is upwards, like an A, is called an *anticline*; a fold which is downwards, like a V, is called a *syncline*. The centre of the fold is called the *crest* of the syncline or anticline, the two sides are called the *limbs* of the fold, and a straight line equally dividing the two limbs is called the *axis* of the fold. The limbs are said to dip at a certain angle to the north, south, east, or west, and so forth, the angle

Fig. 22.—A Whale-back, or Pitching Anticline, rising from the Ground

The arrows indicate the "dip" of the beds, and are laid on the "dip-slopes". The lines at right angles to the shafts of the arrows indicate the "strike" of the beds.

being reckoned from the horizontal. The axis of the fold also dips at a given angle, but the extension of the axis right and left, measured along a horizontal plane, is called the *strike* of the fold. The fold consists of layers of rocks of considerable extent, and the fold

Fig. 23.—The Axis of the Hex River Syncline, pitching upwards at the Worcester end, as seen from Hex River Station

is greatest where the horizontal thrust is largest; at either side the thrust is not so great, the consequent folding is not so intense, and at a certain distance from the centre the fold gradually dies out. There is then a longitudinal dip as well as a transverse dip, and the fold is said to *pitch* along its line of strike. An anticline with a short transverse extension is often referred to as a *whale-back anticline.*

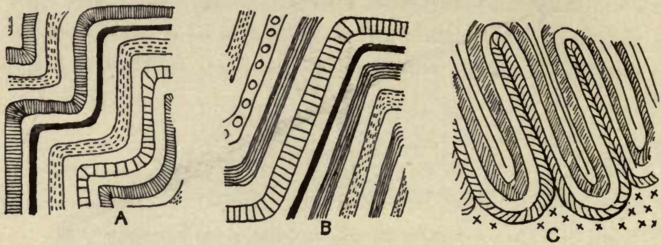


Fig. 24.—A, Knee-bends. B, Monocline. C, Isoclines.

Varieties of folds are of four main types. When the fold is abrupt and angular it is referred to as a *knee bend.*

Fig. 25.—Escarpment of the Gydow Mountains overlooking the Warm Bokkeveld. Two monoclines are shown

When the axis of the fold is inclined, the fold is said to be *overfolded.* If there is only one limb to the fold the resulting structure is called a *monocline*. If both limbs are compressed, and are equally inclined to the horizontal, the fold is called an *isocline*.

In great mountain ranges, such as the Alps, the lateral compression is very great, and the folds are crushed in at the base, forcing the axes to splay out fan fashion. Fan structure, or the collection of a number of folds in

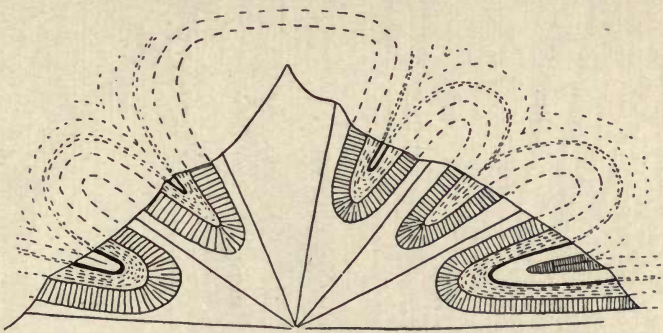


Fig. 26.—Fan-structure in Mountains; the strata have been folded with the axes of the folds splaying out fan fashion. Notice that going up the hill the normal succession is first observed, the lowermost bed being at the bottom and the next succeeding above; further up the order is reversed. The dotted portions of the folds have been removed by denudation. In the outer portions of the folds the beds have been strongly over-folded. Types: Alps and Himalayas.

an arched composite fold, is called an *anticlinorium*, whereas when they are collected into a trough the whole is called a *synclinorium*. A portion of fold in being bent may become crinkled with innumerable small bends. These are so frequent in the great folded mountains of the south coast of South Africa that they may almost be said to be characteristic of them. Gorgeous sections showing this crinkling are exhibited in all stages in Meiring's Poort, Oudtshoorn, but similar folds may be seen along the railway in the Alicedale Poort, on the Midland line. Sometimes the crinkles may be even

Fig. 27.—Meiring's Poort, Oudtshoorn; folded Table Mountain sandstone showing how folds often become obliterated downwards

smaller, and the whole rock is waved in little folds like crinkled paper. This is especially noticeable in the slates near the village of Malmesbury. The Scottish Survey calls this crinkling *concertina structure,* it being extraordinarily well developed in the Highland schists.

An extreme case of folding occurs in the larger folded mountains, where the loop of the fold not only is pushed over but is actually laid flat and thrust out from the centre of the range; recumbent folds of this nature are very frequent on the north of the Alps.

It is evident from the above that folds of any nature whatever occurring in the earth's crust imply that the beds have been compressed. The thrust is nearly always horizontal, but how it originates is not yet perfectly understood. Formerly the thrust was explained by the

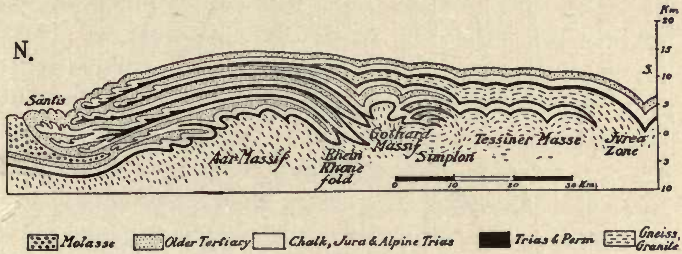


Fig. 28.—Recumbent Folds (Joly)

shrinking of the earth's nucleus as it slowly gave up its heat, and the solid crust enclosing it was, therefore, forced to wrinkle like the skin of an apple which is drying. There are, however, vast areas, like the Rocky Mountains, which have been in tension, and generally we may say that where there is compression in one part of the globe there is an area of tension compensating for it somewhere else, and the earth as a whole is not shrinking. Investigation into the problem of horizontal thrusts is proceeding on the lines of the investigation of the expansion caused by the sinking of beds owing to the loading of the sea floor by sedimentation. This is always going on, and the expanded beds, helped by the intrusion of igneous rocks, exert sufficient thrust to form mountains.

Faults.—The earth's crust is like an immense arch spanning the central nucleus. If one pulls a little apart the two sides of an arch, the keystone will fall downwards; if the earth's crust be pulled apart, a strip repre-

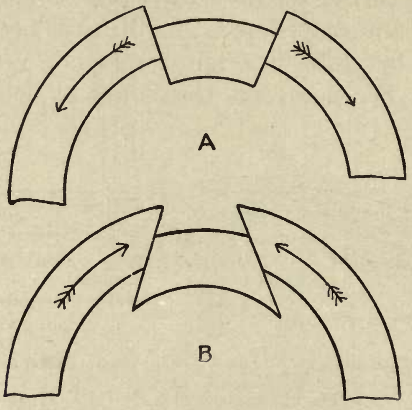


Fig. 29.—Diagram showing why a Normal (tension) Fault must always Hade towards the Downthrow as in A. In B, had the central block merely fallen in, there would be spaces between it and the enclosing segments. As there are no spaces the segments on either side must have pushed over the central block. The fractures in B, therefore, are reversed or thrust (pressure) faults, and the faults hade towards the upthrow.

senting the keystone will fall downwards. The block that has sunk is said to be faulted, and the breaks on either side are called *faults*. In the matter of folds we saw that the beds became inclined, and the inclination or dip was measured from the horizontal; that is because folds are most conspicuous in mountains and on the surface of the earth, where the most important plane by which we orientate ourselves is the horizontal. Faults, on the other hand, are seldom very well marked on the surface, but they are conspicuous in mining operations, where they often displace the lode; and in a mine, where one is constantly thinking of the depth that one is below the surface, in other words, where the vertical is the more important plane, all features are referred to this plane, and hence the inclination of faults is measured from the vertical. It is called the *hade*, to distinguish it from the dip. Faults, then, are planes along which rocks have broken across; one side has sunk, the other remained stationary. The side that has sunk is called the *downthrow side*, and the amount of the sinking is called the *throw* of the fault. The fault plane hades towards the downthrow side, as is obvious from the illustration of the keystone of the arch; if the keystone were to be cut with the top narrower than the base, when the arch is pulled apart the block would not fall in and occupy the vacant space, but would leave that space empty. Faults which run parallel to axis of folding are called *strike faults*, those which cut across the axis of folding are called *dip faults*. The largest fault in South Africa is the Worcester Swellendam fault, with a throw of over 2 ml. vertical on the south.

Rift Valleys.—Faults were illustrated by the pulling apart of an arch, when the keystone would sink. The earth's crust is a vast arch, and it has been pulled apart in places, allowing extended strips to sink downwards between parallel faults; the sunken region constitutes a trough fault, or, in the larger cases, a rift valley. This structure, in its grandest development, exists in East Africa: the rift begins along the Shiré River, extends northwards, includes Lake Nyasa, and then branches. The western branch includes Lake Tanganyika, Lakes Kivu and Albert, and then turns north-eastwards to

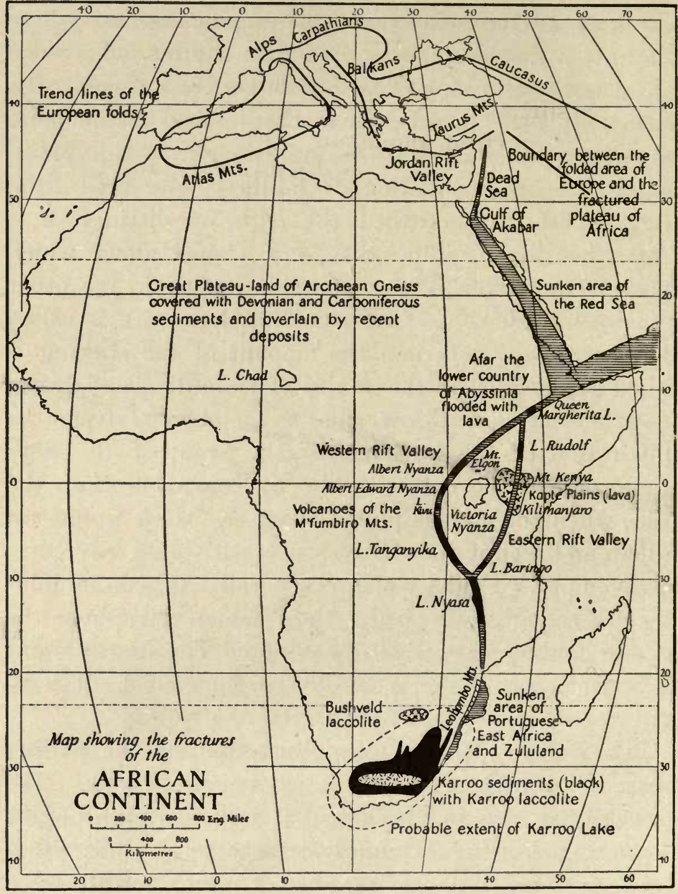


Fig. 30

meet the eastern branch that comes north through Lakes Manjara and Rudolf. Reaching the Abyssinian plateau, the rift widens enormously, and includes both the Red Sea and the Gulf of Aden. North of the Red Sea the rift includes the Gulf of Akaba, the valley of the Jordan, the Dead Sea, and Lake Tiberias, and is finally cut off north of the last by the Alpine folds that here run eastwards into Asia. The fault scarps on either side of the rift are often stupendous; in Lake Nyasa they rise abruptly 8000 ft. above the level of the lake, and in Tanganyika, on the western side, they are 6000 to 7000 ft. high. In the Dead Sea the surface of the lake lies 1286 ft. below sea level; the Judæan hills, in the west, rise to 3281 ft.; and from here to the bottom of the lake, 2625 ft. below sea level, there is a drop of nearly 6000 ft., the throw of the fault. Volcanoes are common along the faults. The M'fumbiro Mountains, north of Lake Kivu, are volcanoes that are connected with the faulting, and they are exceedingly important, because they are of quite recent origin, and before they poured out their lavas into the rift valley the waters of Lake Tanganyika found their way into the Nile, whereas the way is now barred, and the Tanganyika drains into the Congo. It should be recalled that the volcanoes of the Drackensberg in a similar way turned the waters of the streams flowing into the Indian Ocean into the Orange River, which empties into the Atlantic. It is possible that the Drakensberg are on the southern extension of the Great Rift Valley system. So stupendous are these rift valleys in Africa that one is apt to forget that similar rift valleys exist in many other places, such as in the Great Glen that traverses Scotland from the Firth of Lorne to the Moray Firth, and Loch Lochy and Loch Ness are lakes similar to the Tanganyika and Dead Sea. The upper valley of the Rhine, also, lies in a rift valley. There is good reason to believe that the canals on Mars are of this nature.

In South Africa there is a system of rifts similar in

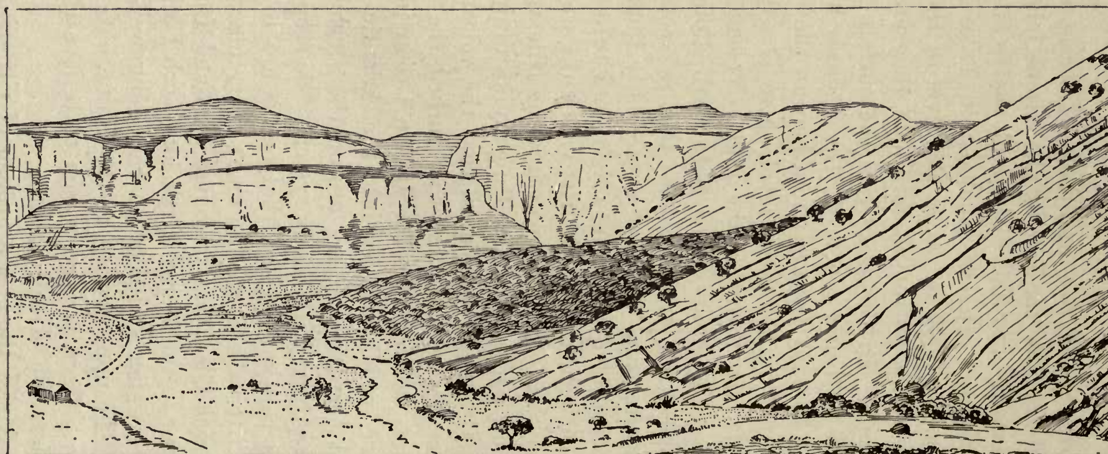


Fig. 31.—The inside of a Baviaan's Kloof fault-pit.
The fault-scarps on the north are of the same nature as those in the great Rift valley of Central Africa

many respects to that of the Great Rift. The most perfect is that of Baviaan's Kloof. A strip of country a mile or two broad has been faulted between steep folds and faults, but the main trend of the fault valley has been interrupted repeatedly by blocks that have remained unaffected, so that the rift valley presents a succession of fault pits separated by high ground. On the eastern extension of the fault system two little

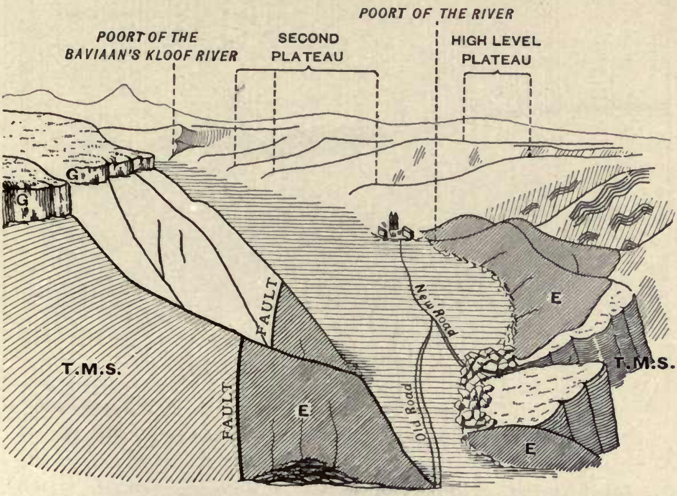


Fig 32.—Another view of a Baviaan's Kloof fault-pit showing the steep fold on the south and the fault on the north, the 4000-feet peneplain, and a subsidiary peneplain formed owing to the temporary barring of the river

E, Enon (Cretaceous) gravels. T M S, Table Mountain sandstone. G, Hardened gravel and sand.

volcanoes occur on the farm Mimosa, near the station of that name on the Midland line. The Baviaan's Kloof fault pits were at one time filled with loose Cretaceous gravels, but most of this material has been carried away by the rivers, and the walls of the pits stand up 800 to

1000 ft. above the floors. In other fault pits, in Oudtshoorn, Robertson, Swellendam, Riversdale, and Heidelberg, the loose gravels still fill the fault pits up to the brim, and the extraordinary case occurs that a more or less circular hole has been, as it were, punched in the

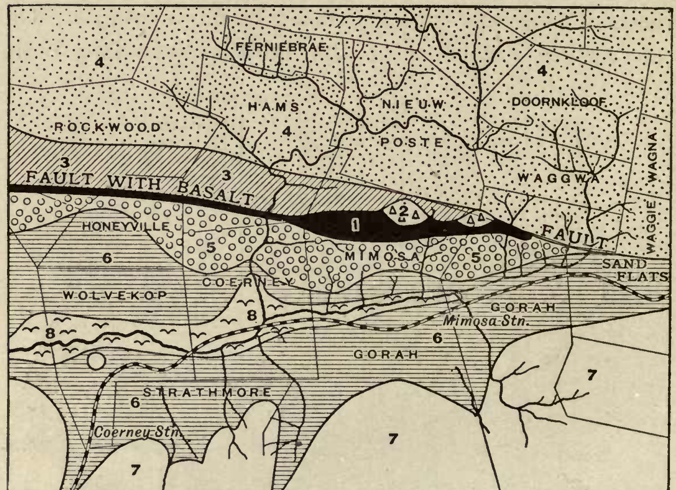


Fig. 33.—Map of the Mimosa area, showing the Fault letting down the Cretaceous beds

1, Basalt. 2, Tuff. 3, Dwyka conglomerate. 4, Witteberg quartzites. 5, Enon conglomerate. 6, Wood bed. 7, Alexandria beds. 8, Alluvium.

earth's crust, and a plug of rock foreign to the neighbourhood has been inserted, just as a carpenter might fill in a hole with a plug of wood.

Reversed faults are folds that have broken across the axis, and have allowed one side to be thrust over the other. The plane of fracture is not a fault plane, properly speaking; it is a thrust plane, and the reversed fault is more properly called a *thrust fault*, or simply a *thrust*. Thrusts can only occur in areas of compression, and are of stupendous dimensions in old mountain lands. The most famous area for thrusts is in the north-west Highlands of Scotland, where segments of the earth's crust have been pushed over one another, as the scales of half-congealed wax may be pushed over one another on a polished table, only in the Highlands the scales have ridden over one another with a

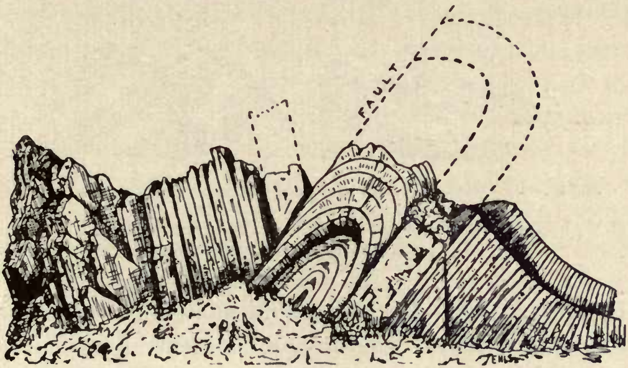


Fig. 34.—Fold in the Zwartberg mountains, Angelier's Bosch, near Prince Albert, Cape Colony. It will be noticed that the lower portion of the fault has been thrust under the upper; it is therefore a "lag fault".

displacement of as much as 10 ml. The term *lag fault* is applied to the unusual case where the lower portion of the fold is pushed forwards under the upper.

Outcrop.—Rocks laid down originally in horizontal layers may be folded and faulted. The tops of the folds and faults may be planed off by weathering and erosion, or cut into peak and valley. The beds, therefore, appear at any one place tilted, the angle of tilt being measured from the horizontal, and called the *dip*. As one follows any one bed over hill and valley it will be exposed in a certain undulatory line, according to the irregularities of the surface; this line is called the *outcrop* of the bed. If the bed outcrops on a horizontal plain, the outcrop becomes the *strike*; the strike is at right angles to the dip. A geological map of a district gives the outcrops of the various beds seen from a bird's-eye point of view; the smaller the scale the nearer the outcrops approach the strikes of the beds, for the undulations in the course of the outcrop become too small to be inserted.

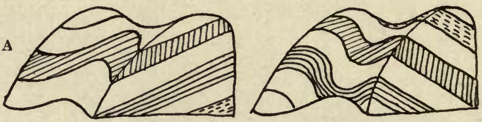


Fig. 35.—Two Blocks of Strata with Beds dipping in opposite Directions

Both are hollowed out as by a river course. In A the "outcrop" points upstream, and in B the outcrop points downstream.

Igneous Action.—Rocks become molten in the deeper layers of the crust; whether by the central heat or by solution does not immediately concern us. The liquid rock moves upwards, thrusting apart the sedimentary or other rocks, or melting out cavities for itself by absorbing the walls of its chamber. The molten rock is said to be intruded into the earlier rocks. If the liquid magma or fluid rock does not rise very far, but solidifies in an enormous lump in the deeper portions of the earth's crust, the mass is called a *plutonic boss*. Examples of these are the bosses of granite in the Western Province, such as that forming the base of Table Mountain, the Paarl and Paarde Bergs, the great masses of granite at George, and that which occurs between Johannesburg and Pretoria. If the granite is harder than the rock it has intruded, denudation causes it to stand out as a mountain, as is the case in the Paarl; but if the intruded rocks are harder, then it is the granite that forms the low ground, as is the case between Johannesburg and Pretoria.

The plutonic rocks—granite most commonly—when they work up into the cavities they finally occupy, exert considerable pressure, and the sedimentary rocks are pushed apart, so that their bedding planes lie parallel to the sides of the bosses. The edge of the granite frequently exhibits a kind of bedding: the minerals—quartz, felspar, mica, and so forth—are arranged in bands, and this banded granite is called an igneous gneiss. It is due to the pressure causing the minerals to separate out in zones, or it has also been explained as being due to movement when the granite was not quite solid, which dragged the minerals out into trains. At some places, as at Robertson, the pressure has squeezed the igneous magma in between the bedding planes of the surrounding sedimentary rocks in very fine layers, so that one can hardly tell where the granite ends and the sedimentary rocks begin; this is called *lit-par-lit*, or bed-by-bed injection. It is possible that this illustrates the way in which the granite makes room for itself; that is to say, the molten magma invades and gradually absorbs the surrounding rocks.

A still further case is when the granite breaks off slabs of the sedimentary rocks, which then sink into the liquid magma. All stages of absorption of these may be observed in South African granites. At Sea Point, on the shore, one may see slabs of slate at the contact lying almost unaltered in the granite. On the road above, however, the granite merely shows dark patches crowded with black mica, which are the remnants of the incorporated blocks of slate. Some people have explained these patches of black mica as segregation patches; that is, areas in which certain minerals have segregated by mutual attraction when the rock was crystallizing.

Dykes. — Smaller masses of liquid rock manage to squeeze into the earlier-formed rocks as arms or dykes. Magnificent examples of such dykes occur in the slate exposed on the foreshore at Sea Point, and were reported on by Clarke Abel in 1818; Hutton used these examples in his famous struggle for the admission that rocks could be intruded.

Dykes may become extended and squeeze up through fissures in the rocks and along bedding planes, widening their channel by absorbing the walls, and so a tongue of liquid rock may travel far from the parent source. A dyke that comes to follow a horizontal plane is called a *sill* or *sheet.*

A dyke may in its course come so near the surface that the impelling force behind it is able to lift up the cover of rocks, and hence a large dome-shaped chamber becomes formed, into which the liquid rock pours and solidifies. At other places the solubility or fusibility of the rocks is more at a particular place than at others, and here the same bulging of the dykes occurs, owing to the liquid magma eating out a great chamber for itself. These expanded dykes are called *laccolites.*

A laccolite may be a single solid expansion of lava, as in the dolerite laccolites of the Insiswa at Mount Ayliff, Mount Currie, and several others on the Drakensberg plateau; smaller ones are to be seen at Cradock and Burghersdorp. Another form is where the central expansion is solid, but round the edge is a fringe of concentric dykes intruded into the sedimentary beds, which they have not had sufficient energy to convert into liquid rock. Such a case is presented by the biggest laccolite, bar one, in the world, the Bushveld laccolite in the Transvaal, which is 250 ml. in diameter, and begins a short distance north of Pretoria; the town itself lies on the complex of dykes that surround the central core.

In yet other cases the expansion does not form a solid nucleus at all, but the igneous matter on its way upwards breaks up into innumerable dykes or sheets; this is the cedar-tree type of the Americans. The South African example is incomparably the most gigantic laccolite in existence on the earth; it extends right through the breadth of South Africa from Natal to the Atlantic, a distance of 700 ml., and forms a belt 200 ml. broad, running through the Karroo. Individual sheets are from 200 to 300 ft. thick, and can be followed for scores of miles; they rise in steps one above the other, those on the south inclining gently towards the centre on the north and those on the north inclining gently southwards. The total amount of liquid rock that is shown by the dolerite now exposed on the surface would make a sphere 50 ml. in diameter. In the Great Karroo the dolerite is seen capping the line of escarpment which separates it from the High Karroo, and on top of the plateau one is lost in a maze of sheets and dykes of dolerite in all directions. To the east the dolerite country lies in a region of greater erosion, and in places such as at Cradock or Queenstown the whole country is one succession of towering dolerite-capped hills. Possibly beneath the Central Karroo there lies a solid core of igneous material, and conversely it is possible that before the covering was denuded from off the Bushveld laccolite the sedimentary rocks were riddled with dykes and sheets as in the Karroo dolerite. The two laccolites are very similar, the northern one being older than the southern one. Dykes belonging to the Transvaal one are diabase, which is a dolerite which has become altered by extreme age, otherwise the peripheral zone of both is the same. To the south of the Transvaal laccolite lies the folded zone of the Witwatersrand, which is a mountain region planed down by long-continued denudation. To the south of the Karroo laccolite lie the great folded ranges of the coast; in both cases the folding is due to the thrust which the intrusion of so much new material into the crust has occasioned.

Metamorphism is the alteration of rocks by pressure, heat, and solvent water. The change is manifested by the substance of the rock recrystallizing in new forms, or by new minerals being introduced from outside. Time is a most essential factor also; none of the results produced in nature could be copied in the laboratory during a man's lifetime. Igneous rocks may be metamorphosed, but besides zones of crushing, which produce crumbled rocks, *mylonites*, the only common metamorphic igneous rock is hornblende schist, which is metamorphosed dolerite. Our attention will be, therefore, concentrated on the metamorphism of sedimentary rocks.

Regional metamorphism, often called dynamo-metamorphism, is the change produced in rocks by pressure, as contrasted with that produced by the contact of intruded molten rocks. Two kinds of pressure have to be considered: dynamic pressure, where the pressure—either the load of superincumbent rocks or the squeeze occurring when a portion of the crust is thrust in any direction and meets an obstacle—causes the rocks to spread out at right angles to the pressure as a lump of dough does when one pushes one's fist into it. Static pressure occurs when the rocks are able to sustain the load like a liquid enclosed in a water-tight compartment; no movement occurs but intense alteration occurs in the rocks under the sustained pressure.

There are three zones into which we can divide the metamorphic rocks. In the first, mechanical crushing and shearing is most marked. To this zone belong the quartzites, phyllites, chlorite- and talc-schists, and the schists with the lustrous white mica, sericite. In the second zone the crystals formed occupy a smaller space than the substance of which they are composed did in the original rock. To this zone belong the quartzites, marbles, the true biotite and muscovite schists, and a few of the gneisses, that is, schists with felspar, such as the hornblende gneisses. In the deepest zone the pressure is nearly entirely static, and the rocks approach the igneous rocks in the nature of their crystalline structure; the schistose and banded structures become less marked, until in rocks like the granulites and eclogites it has disappeared altogether. To this zone belong the biotite and augite gneisses and the granulites. Taking mud as the most complex, chemically, of the sediments, we have the following stages:—

1. Simple compression ... ... Result, shale.
2. Intense compression, some cementing ,, slate.
3. Movement under pressure; thin layers separated by being squeezed out at right angles to pressure; planes of cleavage developed ... ... ,, roofing slate.
4. Development of mica flakes along planes of movement ... ... ,, phyllite.
5. The whole rock recrystallized between

planes of movement, which become planes of schistosity	Result, schist.
6. Felspar introduced from outside obliterating planes of schistosity; rock banded with layers of various minerals; foliation planes	,, gneiss.
7. Banding and all traces of shearing disappear	,, granite.

Sandstones, being more or less rocks containing only the mineral quartz, can only alter into quartzite, but if there is some shaly matrix with the sand grains the sandstone may become a quartz schist.

Limestone alters to marble, but under great pressure its solubility causes it to simply disappear. Thus, in the Kheis rocks of Prieska the limestone bands only occur in places where the pressure has been comparatively small; when they are followed into the areas of greater compression they taper out. The lime frequently goes in solution into the surrounding rocks and causes the development of garnets and other lime silicates.

Contact Metamorphism.—When a tongue of liquid rock intrudes into a sedimentary rock, one would expect to find that the latter was altered at the contact. This does occur; thus, in the coal mines of Indwe and Cyphergat, dykes of dolerite pass through the coal seams and a yard or two of the seam next the dolerite is anthracitized, that is, has all the gaseous content removed and is in the condition of coke. In most of the dolerite contacts the alteration is quite insignificant; the shales are occasionally bleached and hardened, at other places nodules of chlorite and white zeolites appear in the slate near the contact. Real metamorphic mineralization occurs in the Free State, where olive-brown vesuvianite and brown garnet are sometimes found in the slate near the dolerite.

Round the plutonic bosses the metamorphism is sometimes more intense, at others entirely absent. The granite of Cape Town has produced a feeble spotting or knotting of the slates near the contact, that is, small, lightish, hard lumps have been caused to form. At Stellenbosch the slates have been changed to biotite schists at the contact.

Sometimes substances are transferred from the igneous magma to the sedimentary rock; felspar, for instance, may be so conveyed, as along the dolerite dykes at Cradock, or along the granite dykes of Stellenbosch. In the latter case the crystals grow to an inch or more, and a similar occurrence of andalusite in the schist at George, near the granite contact, is of the same nature. The granite, being a muscovite granite, required all the potash for itself, and therefore, instead of handing over potash aluminium silicate to the sedimentary rock to form potash felspar, it transferred only the aluminium silicate, which is the composition of andalusite.

In the Transvaal, round the Bushveld granites, the spots and knots at the contact grow into small crystals of chiastolite or staurolite, while at other places the whole rock is turned into a flinty hornstone by being impregnated with new silicates of the same nature.

Pneumatolitic Action.—This is alteration of rocks by the passage through them of mineralizing vapours. The commonest example is the passage through granite of fluorine and boron compounds in the condition of vapour, which causes the development in the rock of fluorspar, tourmaline, and topaz. Tin and tungstic chloride may come up in a similar way, and in meeting with water decompose, forming crystals of tinstone and wolfram. Corundum, or emery, is deposited in the same way, but not in the tin-wolfram series. Minerals deposited in this way lie scattered throughout the rock in which they occur, and such a deposit is called a *stockwork* in contradistinction to an ore-vein, because the ore has to be won by working out the whole rock in chambers, one above each other, like the rooms of a house (*Stockwerk*, German for a story of a house).

Ore Formation.—There are two schools of mining geologists who hold opposite views as to ore formation. The one, the Ascensionist School, regards ores as having come up in crevices from the interior of the earth in solution, the water even being supposed to be original magmatic water held in the centre of the earth, and coming to the surface for the first time. The other school, the Lateral Secretionists, relying on the fact that all rocks, if analysed sufficiently carefully, show traces of practically every metal known, maintains that the water percolating downwards from the surface dissolves out certain of these metals when it arrives in zones of great pressure, and then, if there is a crevice, the water oozes in, the pressure becomes lessened, the solvent power of the water is reduced, and the substances in solution become precipitated. Both views hold much that is true, but the facts that are important to notice are, that ores are deposited in fissures in the earth's crust from solution in water, and that they can only form in any abundance in those portions of the crust which have been deeply buried, and have been exposed on the surface only after the lapse of enormous periods of time during which the overlying rocks have been removed by denudation. The pneumatolitically deposited ores are, of course, excepted from this category.

A crevice exists in the earth's crust, water containing substances in solution seeps into it through the pores in the rocks composing the walls, pressure is relieved, the substances are deposited. Worthless minerals, such as quartz, calcite, fluorspar and barytes, are called *gangue*, the valuable substances, metals like gold, or metallic minerals such as the sulphides of copper, silver, and so forth are called *ores*. The gangue and ores are deposited on the walls of the fissure, and the material accumulates till the whole fissure is filled in. Subsequently the fissure may open once more, and another deposit of minerals will take place, and so on, so that in many cases there are six or eight separate infillings of one and the same fissure. The fissure thus filled in is called an *ore vein*, or, if quartz is the gangue, a *quartz vein*.

If the vein is now exposed by the removal of the rocks above, the portion which is exposed to the free circulation of water from the surface, which contains oxygen, becomes altered. The sulphides are changed to oxides and carbonates. Also, this oxidized zone usually contains a secondary deposit of the ore by reason that the portion that has been removed by denudation has yielded a certain amount of its mineral contents to the water on the surface, and this sinking in has enriched the top of the vein. Surface enrichment may cause the top 100 ft. or so of a vein to carry ten or a hundred times as much ore as the unaltered vein. At the extreme surface the vein is usually heavily charged with iron oxide, forming a black scoriaceous mass; this is the gossan of the Cornish miners.

Ore veins, when they are exposed to denudation, crumble, as all exposed rocks do, and the heavy minerals in them become separated naturally from the lighter gangue. The minerals may be washed down by rivers and collect in alluvial patches, where by washing the alluvial gravels the minerals may be recovered. The most frequent application of this method is in gold washing; gold occurring in river gravels is called placer gold. Tin is commonly met with under the same circumstance, and such alluvial tin is called stream tin. The bankets of the Rand are old river gravels hardened and compacted, and the patchy nature of the original placer gold averaged by water circulating in the matrix when the rock was deeply buried, and the water, being under great pressure, acted as a powerful solvent.

SECTION IV

STRATIGRAPHICAL GEOLOGY

On the corner of a building in Grahamstown the whitewash had peeled off, and there stood revealed a name painted on the wall which had long been covered. There were two layers or strata of material on the wall; the older, with its peculiar characteristics, became exposed by the removal of the younger. So in the innumerable strata of the rocks, the older are revealed on the surface by the younger being removed by denudation, and each layer, having its own peculiarities, can be recognized in widely separated regions. The order of the superposition of the rocks is always the same; just as in the illustration of the house the more recently applied whitewash could never be found under the older coating bearing the inscription, so the more recently deposited sediments can never be found under the older ones.

The facts one relies upon to determine whether a rock is young or old are, firstly, the nature of the fossils contained in the particular stratum, that is, the palæontological evidence; and secondly, the mineral constitution of the stratum, that is, the lithological evidence. Werner was the first to recognize that there is a definite order of the superposition of rocks, and he grouped the various sediments into four main divisions: those very much altered, *Urgebirge*, which we now call Archæan; those in a transition state, *Uebergangsgebirge*, which we call Palæozoic; those showing normal stratification, *Flötzgebirge*, which we call Mesozoic; and those not yet consolidated into definite strata, *Aufgeschwemmtes Gebirge*, which we call Tertiary and Recent. It was William Smith, however, who first worked out the arrangement of rocks in detail. He was a land surveyor who, in surveying the banks of canals and the cuttings made for roads, noticed that wherever he went certain rocks with characteristic fossils were always underlain and overlain by similar rocks, each with their own characteristic fossils. Smith's *Tabular View of the British Strata* was published in 1790, and his first geological map of the whole of England was published in 1815. Since then the knowledge of Stratigraphical Geology has increased enormously; geologists have penetrated every corner of the globe, and a geological map of the whole face of the earth is now in course of publication.

In South Africa geological investigation was begun by Dugald Carmichael (1817) and Clarke Abel (1818), who wrote descriptions of Cape Town. Dr. Lawrence Jamieson, who was district surgeon at Grahamstown in 1828, wrote descriptions of the Eastern Province; but the first serious work was done by Andrew Geddes

Bain, a road surveyor like William Smith. An account of Bain's work, together with the first map of South Africa, was published in the *Transactions of the Geological Society of London* in 1856, although the material was forwarded from South Africa in 1852. The next map of South Africa was published in 1872 by E. J. Dunn, who was actually the first Government Geologist, and subsequent editions appeared in 1875 and 1887. In 1896 the geological survey of Cape Colony was instituted, and shortly afterwards the surveys of the Transvaal and Natal, and recently the geological surveys of German South-west Africa and Rhodesia. The mass of information is now enormous, but the country is so vast that it is very difficult to join up the work in different regions and weld the whole into an understandable scheme.

In dealing with rock strata, directly one finds a fossil, there is a definite means of establishing the age of the rock, as determined by the European scale of superposition of rocks. In South Africa, however, most of the rocks are unfossiliferous, and comparison by mineral structure is uncertain, therefore there is great confusion in the nomenclature. Mostly geological surveyors in studying any one district find a series of beds which have certain characteristics, and these are given local names. In an adjoining district, other rocks occur with other characteristics, and new local names are given, and so on, till the geology of the unfossiliferous rocks of South Africa has become a mere catalogue of names. Certain broad principles, however, have emerged, and if the student is mystified by the prolixity of systems in the unfossiliferous rocks, he must console himself with the fact that they are pioneer attempts at the understanding of the country, and that the time has not elapsed, nor

TABLE OF EUROPEAN AND SOUTH AFRICAN STRATA

EUROPEAN.		SOUTH AFRICAN.
Cainozoic Group—		
Quaternary System.	Alluvium. Drift.	Alluvium, estuarine deposits. Diamond gravels. Sand dunes.
Tertiary System (Europe).	Pliocene Series Miocene ,, Oligocene ,,	Plateau gravels.
	Eocene ,,	Alexandria System.
Mesozoic Group—	Danian Series	
Cretaceous System (Europe).	Senonian ,, Turonian ,,	Pondoland System.
	Cenomanian ,,	Zululand System.
	Albian ,, Aptian ,,	
	Neocomian ,, (Wealden, freshwater).	Uitenhage System.
Jurassic System (England).	Purbeck Series. Portland ,, Kimmeridge ,, Coral Rag ,, Oxford Clay ,, Kellaway's ,, Great Oolite ,,	
	Inferior Oolite ,, Lias ,, Rhætic ,,	Stormberg System. Cave Sandstone Series. Red Beds Series.
Triassic System (Europe).	Keuper Series. Muschelkalk ,, Bunter	Molteno

Upper Palæozoic Group—		Idutywa Series.
Permian System (Europe).	Zechstein Series.	Beaufort ,,
	Rothliegende ,,	Ecca ,,
		Dwyka ,,
Carboniferous System (England).	Coal Measures Series.	
	Millstone-grit Series.	
	Mountain Limestone Series. (Culm Series.)	Witteberg Series.
Devonian System (America).	Catskill Series.	
	Chemung ,,	
	Portage ,,	
	Tully Limestone Series.	
Old Red Sandstone (Scottish freshwater *facies*).	Hamilton ,,	Cape System.
	Marcellus ,,	
	Upper Helderberg ,,	
	Oriskany Sandstone ,,	
	Lower Helderberg ,,	Bokkeveld Series.
Older Palæozoic Group—		
Silurian System (England).	Ludlow Series.	Table Mountain Series.
	Wenlock ,,	
	Llandovery ,,	
Ordovician System (Wales).	Bala Series.	
	Llandeilo ,,	
	Arenig ,,	
	Tremadoc ,,	
Cambrian System (Wales).	Lingula Flags Series.	
	Menevian ,,	
	Caerfai ,,	
Azoic Group (ARCHÆAN)—	TRANSVAAL.	CAPE COLONY.
Torridonian System (Scotland).	Waterberg System.	Matsap System.
Algonkian System (America).	Transvaal System.	Transvaal System.
	Witwatersrand System.	Kheis System.
	Swaziland System.	Malmesbury System.
Lewisian System (Scotland).	Gneiss and Swaziland Schist.	Gneiss and Namaqualand Schist.

has the number of geologists who have studied the questions been sufficiently great, for the perplexities to have been unravelled.

The sedimentary rocks of Europe and America are divided into four main groups, on the principles laid down by Werner. These are now classed according to whether they have no fossils, or whether the fossils are the remains of primitive type of animals, or of animals intermediate between these and the recent forms, or, finally, of animals nearly allied to recent forms. The actual terms are Azoic, with no life; Palæozoic, with ancient life; Mesozoic, with intermediate life; Cainozoic, with recent life. If we wish to speak of the time during which the group of rocks was deposited, we use the term *era*; thus the Mesozoic Era is the time when the great reptiles lived on land and ammonites lived in the sea.

Groups are divided into Systems, corresponding with Periods of time.

Systems are divided into Series, corresponding with Epochs of time.

Series are divided into Stages, corresponding with Ages of time.

Stages are divided into Zones, corresponding with Hemeræ of time.

Zones are divided into Strata or individual Beds.

In South Africa we have two main groups of beds; to the newer one, because it extends from the Palæozoic to the Mesozoic, we cannot apply either of the European group names; and an older group, which, though being in the literal sense "Azoic" as far as investigation has gone, may at any time yield fossils which might put the particular system into the Ordovician or Cambrian. Two separate group names are thus requisite: the newer beds of South Africa, from the Cape System upwards, are called the Neo-Afric Group; and those below the Cape System the Pre-Cape or Pal-Afric Group.

The systems in the Cape and Transvaal are not yet correlated; their parallelism in the Table means that they occupy about the same position. There are, in addition, many smaller systems which will be noticed in due course, but which are not included in the general Table.

CHARACTERISTIC ORGANIC REMAINS FOUND IN THE STRATA

Cainozoic.	Quaternary Man. Tertiary Monkeys.	Nummulites.		
Mesozoic.	Cretaceous Birds. Jurassic Mammals. Triassic.	Ammonites and Belemnites.		Flowering Plants.
Younger Palæozoic.	Permian Reptiles. Carboniferous Amphibia Insects. Devonian.		Trilobites.	Land Plants.
Older Palæozoic.	Silurian Fish. Ordovician Corals. Cambrian Brachiopoda, Mollusca.	Graptolites. (Silurian, Ordovician)		

The organisms mentioned make their first appearance at the horizons indicated, and those in brackets are confined to the strata to which the particular bracket refers.

The general arrangement shows that the younger the beds the more highly organized are the remains of the animals or plants found in them; and, conversely, the older the beds the more primitive the type of organisms. There are two general facts which must be noted. In the first place, the first beds in which organic remains are found contain fossils of animals in an extremely high state of development. The Trilobites of the Cambrian are animals something like woodlice, though they lived in the sea, with well-developed eyes implying a brain, complicated legs, and generally showing that they must have had a long line of ancestors from whom they inherited their good qualities. The mollusca of the Cambrian include the Nautilus, which is a very highly organized animal, something like an octopus in a shell. The whole collection of animals, therefore, of these extremely old beds show that the strata laid down previously to them must have contained organic remains, but we have not yet found them. Possibly the ancestors of the Cambrian animals all possessed soft bodies unprotected with shells or armour, and therefore left no trace in the sediments when they died; or, again, all the beds that contained them have suffered such squeezing and alteration that any organic remains that might have been in them may have become unrecognizable. Neither of these cases, however, is probable; the beds containing the remains of the ancestors of the Cambrian animals will one day be found, though it may be that the greater part of them are under the sea or covered with later sediments.

The second point is that though whole groups of animals have at one time flourished on the face of the earth or in the waters covering it, and have died out completely, like the Nummulites, Ammonites, Belemnites, Trilobites, and Graptolites—and the same is true to a much greater extent in the genera and species of various classes of animals—yet there are cases in which animals have persisted unaltered from remote times to the present day. The most striking example is the little tongue-shaped brachiopod, Lingula, which is abundant in the Cambrian and still exists in the sea. The Nautilus of the Cambrian, again, is closely allied to the modern pearly nautilus; and, lastly, the Ceratodus, or Australian mud fish of the present day, is found in the deposits laid down in the lakes of the Triassic times. The age of a particular bed, therefore, must not be judged from one or two specimens of fossils, but the whole group of animals or fauna that lived when the sediment was laid down must be taken into account. In freshwater deposits it is the collection of the remains of plants, or the flora, which is important. Unfortunately, however, they are much less frequently preserved than animals.

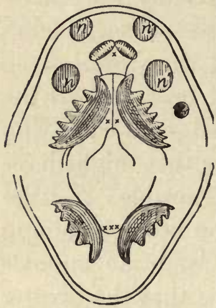


Fig. 36.—Mouth of *Ceratodus*

nn, Narial openings. *x*, Vomerine teeth. *xx*, Palato-pterygoid teeth. *xxx*, Mandibular teeth.

It will be noticed in the Table of Strata that the South African Devonian Rocks are correlated to, or paralleled with, the American, not the European marine, Devonian. This is because the South African fossils correspond to the American and not the European forms. This, then, shows that beds may be contemporary and yet may not contain similar fossils. The reason why this happens is that in this particular case the sea in which the animals lived, whose remains are found in the European rocks, was separated by a vast land barrier from the American and South African sea, which existed at that time, and the animals that lived in the two oceans were different, as is the case now with the animals which live respectively in the Atlantic and Pacific Oceans.

The converse holds good: beds containing similar fossils may not be contemporary. Take as an illustration the cave deposits of the south of France. In any one cave one may find three layers overlying each other. The bottommost contains the hearths, burnt wood, implements, and finally the bones of an ancient race of men called the Mousterians. After they had left, the cave was filled in with dust and mud, and a new race of men came in and cooked their food on the new floor, and in turn left their implements, and in the end their bones, in this layer: these were called the Magdalenian men. Lastly, a third race, the Solutrians, came and occupied the cave, leaving their bones in the uppermost layer. Now, the Mousterians have been identified with the Australian aborigines, the Magdalenian men with the North American Indians and the Patagonians, and the Solutrians, with the Bushmen of South Africa. It is evident that a very great lapse of time has occurred between that in which these peoples occupied the south of France, and the present time; but the soil forming at the present day is being filled up in the respective countries with the bones of the buried races of Australians, North American Indians, and Bushmen; and these beds, therefore, though containing the same organic remains as the layers in the caves of the south of France, are very much more recent. The coal plants of Europe, again, migrated from the Southern Hemisphere, so that the beds containing the coal plants in South Africa are much earlier than the rocks of Europe containing the same forms. Sediments containing the same fossils, but not contemporary, are called *homotaxial*. Homotaxis, then, means the same fossils but the beds containing them not contemporaneous.

It has often happened in the geological history of the globe that one area has been dry land at one period and sea at another. While the area is dry land no deposits are laid down, and therefore the animals that swarmed in the seas at that time elsewhere, and became embedded in the sediments when they died, had no chance of being represented in the area in question. Thus, in South Africa all the forms that occur in the Cambrian, Ordovician, and Silurian rocks of Europe, Asia, and America are not found. While the sediments of these periods were being deposited, South Africa stood out as dry land above the sea, and the whole era is represented by the unconformity at the base of the Table Mountain Sandstone. Another possibility may happen, namely, that the area in question may be covered with a freshwater lake. The Karroo sediments were laid down in a lake, and therefore the animals whose remains are found in the Karroo sediments are totally different from the animals found as fossils in the marine Trias and Permian of other countries. Conversely, the Devonian rocks of South Africa are marine, whereas the Devonian rocks of Scotland are freshwater deposits, and the fossils of the Scottish freshwater beds, or, as they are called, the Old Red Sandstone, are freshwater fish and giant water-scorpions—forms unknown in our beds.

The Transvaal, Cape, and Karroo Systems consist of conformable series of beds one above the other; but it is evident from the table that there is a gap in the time succession represented by Bokkeveld and Witteberg Series, although the two rock series follow each other without a break. This may be due to the fact that the scale as worked out in England or America is not a correct one as regards the time succession; indeed there are so many gaps in the rocks, caused by land periods when no sediments were laid down, that it is hardly likely that it is perfect. But still the scale must be in the main correct, for it can be applied to the rock succession in far-distant parts of the earth. More probably the Bokkeveld-Witteberg gap is due to the fact that the Bokkeveld sediments, which were laid down in deep water, became less and less as the sea floor sank and the shore line retreated, till finally sedimentation ceased over the area now covered with Bokkeveld Beds. It must be remembered that detritus from land, even the finest muds, is not carried beyond 200 ml. from the shore. When the sea floor began to rise again, the succeeding Witteberg sediments would follow the previous ones conformably; but there might thus be a considerable time interval between the last of the Bokkeveld Beds and the first or lowermost of the Witteberg Beds. Such a conformity, in which succeeding beds skip a period on the time scale, may be called a *per saltem* conformity.

General Arrangement of the Rocks in South Africa.—Africa, as a whole, is a vast plateau land, distinguished from Europe by the fact that there the main geological features are folds which have crumpled up the rocks, whereas in Africa the folds which occur are of extremely ancient date, and have been almost obliterated; and the predominant features are faults of vast extent. Rhodesia on the north belongs still to the main plateau, but in the Transvaal we enter into a new order of things. The main area of the Transvaal is occupied by a gigantic laccolite, which has invaded the ancient beds and pushed them southwards; and at a later date a similar laccolite, or spread of dolerite dykes having the effect of a laccolite, has invaded the Triassic and earlier beds of Cape Colony, and has again pushed them southwards. There are, therefore, three separate areas, and the order of the description will be from the south to the north, as in that way we shall avoid a great deal of repetition, for many occurrences in Rhodesia, for instance, cannot be understood without reference to what is found in the Transvaal, and what is found in the Transvaal can only be explained by comparison with the geology of Cape Colony. The individual formations will be described from below upwards—that is to say, the oldest formations first, and then through successive formations to the most recent.

CAPE COLONY

Pal-Afric Group

Malmesbury Formation

This formation consists of ancient slates and occasional limestones, quartzites, and conglomerates, which occur in the south of Cape Colony. It is a comprehensive term which undoubtedly includes many divisions of rocks of greatly differing age, but which the badness of the exposures does not allow us to properly distinguish. The beds are for the most part highly inclined, and have been crushed into folds, which has obliterated divisions and occasionally produced such metamorphism that the rocks appear to belong to an altogether different system, which perhaps they do.

The typical area is not Malmesbury, where the rocks are metamorphosed to crumpled mica schists, but at Cape Town. Here one finds on the north of the granite a great series of massively bedded slates, clay slates, and slaty sandstones dipping north at a considerable angle, from 45° to 85°. The rocks are blue-black to grey in colour, but on the surface pass somewhat readily into a brown clay in the moister parts. They are quite useless for building purposes, for directly the live rock is quarried, and the water of imbibition dries out, it splits and crumbles to fragments. Passing northwards to Paarl and French Hoek similar rocks occur, with the addition of a bed of conglomerate in the latter place. Still northwards, at Vogel Vley, there are limestone and quartzite bands. In the Tulbagh valley and at Worcester there is a stage intermediate between the clay slate and schist; the rocks are phyllites, and the blue-black rocks are coated on the surface of the cleavage planes with scales of silvery mica. At Worcester, again, there is a bed of limestone. Eastwards, the next important outcrop is at George, where the rocks are thinly bedded or sheared, for it is impossible to distinguish the two planes, and are so carbonaceous that they have been prospected for coal. There are many curious contact metamorphic rocks in this last area, which will be dealt with presently.

North of George, in Oudtshoorn, there is an important area of Malmesbury Beds in the Cango. The southern border of the district consists of high hills of conglomerate like that in French Hoek, but of very much greater thickness, and complicated by folding. The conglomerate—the Cango Conglomerate—apparently rests on thin-bedded slates of the Malmesbury Series, in which are interstratified three main bands of limestone; the famous Cango caves occur in one of these limestone bands.

On the west coast the Malmesbury Beds are exposed on the coastal plateau, all dipping steeply to the west. As the width of the plateau is from 30 to 40 ml., it is manifest that the beds, which cannot as a whole be more than a mile or so in actual thickness, have been bent upon themselves many times. At Van Rhynsdorp, again, limestone bands come in. There are swallow holes, showing that there must be caverns in the limestone, but as the rock is exposed in a flat plain there are no openings, like in the hilly district of the Cango, by which one can explore them.

Above the closely folded Malmesbury Beds at Van Rhynsdorp there comes in another series of clay slates very little folded, the **Ibiquas Series,** so called from the name of the tribe of Hottentots that once lived here. Below the Malmesbury Beds, there is a series of red sandstones and arkoses, called the **Nieuwerust System,** which underlies extensive areas in Namaqualand. Inland, on the north of the Karroo, Pal-Afric beds come in again; but these belong to the Transvaal area, and will be described under the section dealing with that area.

Granite Intrusive in the Malmesbury Beds.—Great domes of molten rock have invaded the Malmesbury Beds all over the area in which they are exposed, and these have solidified as granite. In some places, as at the Paarl and Malmesbury, the rock has resisted weathering so successfully that all overlying rocks and the softer slates which surround it have been cleared away, and the granite dome rises as a magnificent mountain. At other places, as at Simon's Berg, and especially at Cape Town, the granite is still capped with the overlying Table Mountain Sandstone. At still other places, as, for instance, at George, the granite has been worn down equally with the slates, and there is no difference in the relief of the country where it occurs. At Worcester, and the same is found to be the case in several other areas, as at Vogel Vley, the granite dome is not yet properly exposed, but only the ends of the dykes that surround the domes appear at the surface of the ground.

The granite is usually moderately coarse grained, consisting of quartz, felspar, and biotite. At Sea Point porphyritic varieties occur with felspars up to 2 in. in length. At this last place there are inclusions of slate in the granite, which at the periphery are unaltered, but, further in the granite, change to bands of biotite. At Kuil's River, Stellenbosch, and at George the granite becomes a white mica granite, and wherever this occurs there is an abundance of tourmaline with, at least at Kuil's River, the usual accompaniment of tinstone and wolfram. Graphic granite occurs at Camp's Bay, and coarse pegmatite with felspars up to a foot in length at Malmesbury; the dykes at the latter place pass into porphyries. At Platte Klip, above Cape Town, the granite contains cordierite, usually altered to a micaceous mineral, pinite, which is the same as the more massive mineral agalmatolite, found in Bechuanaland, which was used by the Bushmen for making pipes, &c.

The contact phenomena of the granite are confined to the simpler manifestations. At Cape Town there is a slight spotting of the slate, and at Stellenbosch a certain increase of biotite near the contact. At the latter place, also, felspar has come from the granite and crystallized in the chinks in the slate, so that good Carlsbad twins may be obtained up to 1 in. in length. In the case of the contact of the muscovite granite of George there are andalusite crystals instead of felspar, sometimes imperfectly developed as hard knots in the slate, at other places forming well-defined crystals 1½ in. in length.

In Natal the granite has altered the limestone at the contact, and has converted it into marble with garnets, diopside, and olivine; there is a small area of white marble at Worcester which owes its character to the granite below.

Basic intrusions (dolerite dykes) are found running through the granite at Lion's Head at Cape Town, at Vogel Vley, at Kapok Berg in Malmesbury, and at the western end of the Cango. The molten rock has had very little, if any, action on the sedimentary beds. The Vogel Vley dyke is a diabase, that is, an altered dolerite, and is much more ancient than the others, which are probably post-Karroo.

The Neo-Afric Group

The Cape Formation

The Table Mountain Sandstone.—The Table Mountain Sandstone, Bokkeveld, and Witteberg Series form what is known as the Cape System. The lowermost of the three, the Table Mountain Series, rests on the eroded surface of the granite and Malmesbury Beds. The deposition of it and the Malmesbury Beds was separated by a vast interval of time, sufficient to have allowed the Malmesbury Beds to have been hardened, tilted, invaded by granite, and planed down to a more or less level surface by erosion on land, and finally submerged beneath the sea before the sands of the Table Mountain Series were laid upon them. The Table Mountain Sandstone consists essentially of coarse sands piled up in layers at different angles (false-bedded), and every two or three feet separated by a major bedding plane. The colour is blue, but on weathering the rock assumes the predominant grey colour, splotched occasionally with red, which gives the Cape Mountains their characteristic tint.

Very near the bottom there is in some places a well-marked band of deep-red slates, and towards the top a broader band of shales, slates, and slaty sandstones. The upper shale band, as it is called, is remarkable from its

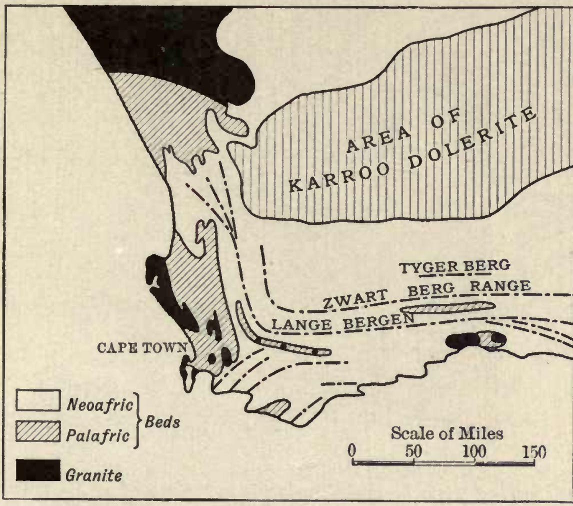


Fig. 37.—Map of the south-western corner of Cape Colony, showing the trend lines of the folds and the area occupied by the great Karroo laccolite

being more easily weathered than the hard sandstones, and therefore it forms a conspicuous depression wherever it occurs, and is very useful in tracing the folds into which the series has been thrown. In the Cedar Mountains, on the western side of the Karroo, the upper shale band contains glaciated boulders, showing that icebergs must have been floating about in the sea in which the sediments were being laid down. Towards the top, but beneath the upper shale band, there are frequently found beds of white quartz pebbles, as at Table Mountain and Oudtshoorn, and these sometimes become regular bands of conglomerate (banket) as at Knysna.

The Table Mountain Sandstone is 5000 ft. thick in its fullest development at Ceres. Northwards it becomes thinner, and eventually wedges out to nothing. At

Fig. 38.—The Witzenbergen from the top of the Schurftebergen, showing the steeply inclined Table Mountain Sandstone near the head of the Witzenberg valley, and the Shale Band at the top of that rock series

Pakhuis Pass, where the road passes into the Olifant's River (Clanwilliam), and along the coast at Van Rhynsdorp, there are coarse conglomerates at the base, showing that the actual beach along the shore was close by. The northern shore has not been satisfactorily traced.

The Table Mountain Sandstone forms the grand chains of coastal mountains which bar the way to the interior along the south-west and southern shores of South Africa. It forms the top of Table Mountain and the greater portion of the Cape Peninsula. On the mainland

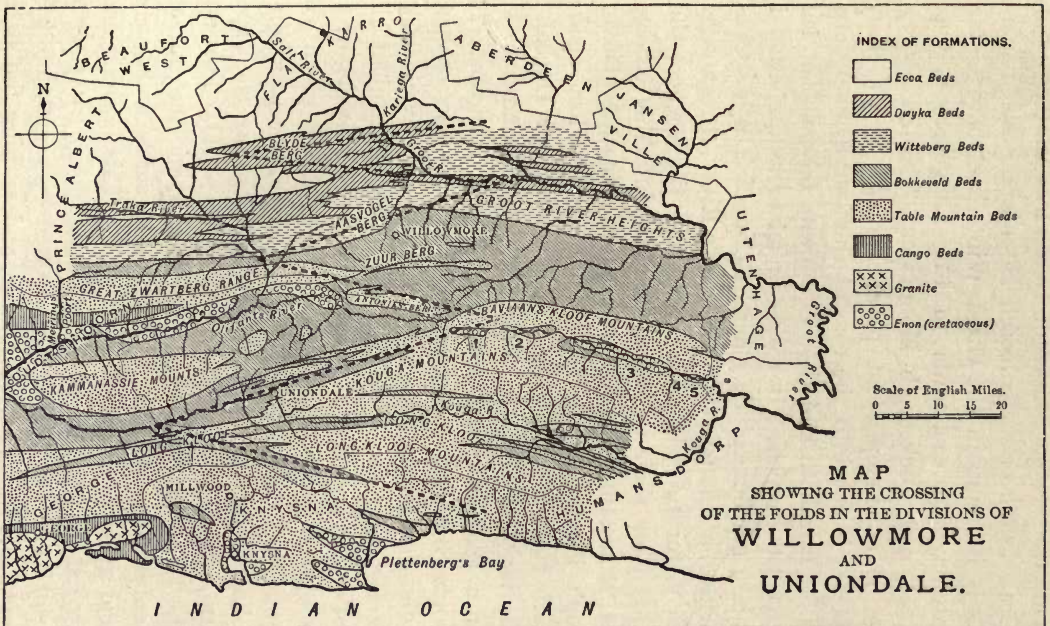


Fig. 39.—Detailed Map of the Folds where they splay out seawards to the east of the granite bosses of George. 1, 2, 3, 4, 5 are the fold-basins or fault-pits of Baviaan's Kloof.

it forms the abrupt ranges of Hottentots' Holland and the Drakenstein or Stellenbosch Mountains; then northwards it is found in the Great Winterhoek and Cedar Mountains, and eastwards in the Langebergen, Outeniquas, and Cockscomb Mountains. The Zwartberg Range is an independent parallel range to the last. The series is cut into the coastal shelf in Humansdorp and Port Elizabeth and then disappears beneath the sea at Cape St. Francis. It comes in again as an isolated mountain surrounded by glacial moraines (Dwyka Conglomerate) at the mouth of St. John's River, the gates of which it forms. Then from Waterfall Bluff, where the streams pour their waters over a cliff into the sea, the Table Mountain Sandstone forms the coastal plateau through Pondoland to Natal, and becomes lost again beneath the glacial moraines somewhere near Durban.

The vegetation of the Table Mountain Sandstone is at once the pride and despair of South Africans. It supports the extraordinary proteas or sugar bushes, the disas, watsonias, gladiolas, heaths, and everlasting flowers of the Cape, which are the most beautiful of all wild flowers, and also the great forests of Knysna, with the majestic yellow-woods, rising 80 to 100 ft. in superb columns, and then branching out into gigantic panoplies of foliage. In the Cedar Mountains there are the Cape Cedars, which grow nowhere else in the world. The soil on the Table Mountain Sandstone is sour, and the grasses can only be eaten when quite young by cattle, and hence the old grass is periodically burnt off. This burning has destroyed first the forests, and is now doing away with the soil itself, for the soil, unprotected by vegetation, becomes washed away by the rains, and nothing but bare rock is left. The Cape Mountains, therefore, denuded of

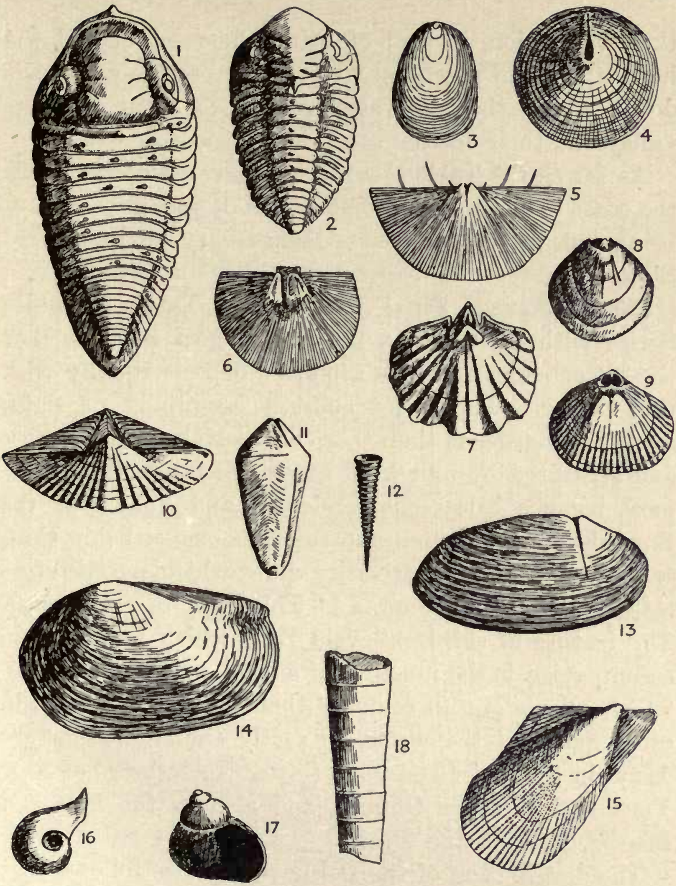


Fig. 40.—Bokkeveld Fossils

Trilobita: 1, *Homalonotus herscheli*, Murch.; 2, *Phacops africanus*, Salter. Brachiopoda: 3, *Lingula densa*, Conrad; 4, *Orbiculoidea baini*, Sharpe; 5, *Chonetes falklandicus*, Morris and Sharpe; 6, *Orthothetes sulivani*, Morris and Sharpe; 7, *Leptocœlia flabellites*, Conrad; 8, *Centronella baini*, Sharpe; 9, *Rensselœria relicta*, Schwarz; 10, *Spirifer orbignyi*, Morris and Sharpe. Pteropoda: 11, *Conularia africana*, Sharpe; 12, *Tentaculites crotalinus*, Salter. Lamellibranchiata: 13, *Nuculites africanus*, Salter; 14, *Palæoneilo antiqua*, Sharpe; 15, *Actinopteria boydi*, Conrad. Gasteropoda: 16, *Bellerophon morganianus*, Hartt and Rathbun; 17, *Holopœa baini*, Sharpe. Cephalopoda: 18, *Orthoceras bokkeveldensis*, Reed.

their vegetation, instead of being the reservoirs of the head streams of perennial rivers, have become pent-roofs down which the rainwater rushes to scour out the valleys at their foot.

As far as the Table Mountain Sandstone occurs along the coast it forms bold promontories or seacliffs, the bays being cut in softer rocks—Malmesbury or Bokkeveld Slates.

The Bokkeveld Series follows the Table Mountain Series with no break, a fact which goes to show that the latter series must be a marine deposit equally with the former. The series consists essentially of slates much less hardened than those of the Malmesbury Series, and separated by four hard sandstone bands, the lowermost being a calcareous sandstone, and known as the Fossiliferous Sandstone, and the three upper being thin-bedded sandstones, weathering white, which are therefore called the First, Second, and Third White Sandstones. The feature of the Bokkeveld Beds which makes them so important is the presence of a large number of fossils, which allows one to compare these beds with others in other parts of the world. Exactly similar fossils are found in the lower Devonian (lower Helderberg) of New York and Western Ontario, and also in the Falkland Islands, Bolivia, and Brazil.

The distribution of the Bokkeveld Series follows that of the underlying Table Mountain Sandstone very closely, forming the low ground at the foot of the mountains. It thins out on the west equally with the Table Mountain Sandstone, but does not reach so far north as that series. On the coast it has been followed as far as Port Elizabeth, and it probably extends some distance to the east, but it is covered with the Witteberg rocks in Albany, Tabular View of the Bokkeveld Series, Gamka Poort, Prince Albert

	Feet.
Lower shales, richly fossiliferous at the base, consisting of shales and thin-bedded sandstones	324
Fossiliferous sandstone; compact blue sandstone not very distinguishable from the lower shales; fossils only occasionally	145
Lower shales above fossiliferous sandstone, very richly fossiliferous at base; shales and thin sandstones ...	125
First white sandstone. Sandstone beds separated by shales; at bottom blue sandstones, then more quartzitic white sandstones, then intensely hard black sandstones, and on top blue compact sandstones; intensely ripple-marked throughout	419
Upper shales, soft grey-bluish or greenish mudstones ...	370
Second white sandstone, compact, blue sandstones beneath, more quartzitic above	85
Upper shales, grey mudstones with occasional sandstones	300
Third white sandstone, compact micaceous sandstones	100
Gritty micaceous shales, mottled green or brown and white, ferruginous in places, and indurated into sandstone bands at varying intervals	600
Total thickness of the Bokkeveld Series ...	2468

and with that system runs out to sea at the Gualana River, and does not appear again with the Table Mountain Sandstone in Pondoland and Natal.

The Bokkeveld Series was at one time confounded with the Malmesbury Series, both consisting of slates, and in many cases the one forming one side of the mountain of Table Mountain Sandstone and the other the other; indeed, at Oudtshoorn, the Table Mountain Sandstone dips under the Malmesbury Beds, and the Bokkeveld Beds dip under the Table Mountain Sandstone, owing to an overfold, but the detailed survey of the country showed that the bottom of the Table Mountain Sandstone was always next to the Malmesbury Beds, and the top next to the Bokkeveld Beds, however much the rocks were folded. If a mountain of Table Mountain Sandstone appears above a plain of Bokkeveld Beds it does so because an anticline brings up the lower beds through the upper; whereas if such a mountain lies in a plain of Malmesbury Beds it is a syncline that has brought the upper beds down to the level of the lower.

The soil in the Bokkeveld is sweet, and is covered with cornlands and vineyards. In the drier parts it bears the peculiar Karroo vegetation, where the plants, instead of spreading their roots through the soil on the surface, have to send them down through crevices where a little soil and moisture is to be found; in other words, the surface is bare rock and the soil is underground.

The Witteberg Series is a series of thin-bedded, close-grained, yellow sandstones, with partings of micaceous red shale. Indeed, one can say it is a fourth white sandstone of the Bokkeveld Series, and the two series have very much in common. Between the last band of quartzite in the Bokkeveld Beds and the first great series of quartzites in the Witteberg Beds there are some 800 ft. of shales The line of division between the two series is taken in the middle of the shale, as it is here that the fossil, *Spirophyton*, first becomes plentiful. It forms the lower hills in front of the great coastal mountains, and is separated from them by a valley of Bokkeveld Beds. It was formerly confounded with the Table Mountain Series. Apart from the fact that it lies above, not below, the Bokkeveld Beds, the differences may be tabulated thus:—

DIFFERENCES BETWEEN THE WITTEBERG AND TABLE MOUNTAIN SANDSTONES

Witteberg Sandstone	Table Mountain Sandstone
Fine-grained, thin-bedded, yellow sandstones; shale partings throughout.	Coarse-grained, massively bedded, grey sandstones; shale bands only at top and bottom.
Fossils: *Lepidodendron*, *Spirophyton*, *Hastimima*.	No fossils; indistinct traces of shells in the shales at the base.

The Witteberg Beds are usually intensely folded, the thin sandstones readily accommodating themselves by that means to stresses, whereas the Table Mountain Sandstone, as a rule, bends into great arches. The close nature of the sandstone prevents the penetration of moisture, so that the coarse-grained Table Mountain Stone is more plentifully supplied with springs than the Witteberg. This character also leads to the rocks, when they are tilted, being exposed in enormous flat slabs. The name of the series is derived from those slabs that face the Karroo, and which are exposed by the overlying Dwyka shales having been removed from off them, but a similar feature is exhibited in the Table Mountain Sandstone in Ceres. Bands of white quartz pebbles may also be present in the Witteberg Sandstone, and towards the top of the series there is usually, in the west at least, a well-marked shale band followed by the top quartzites exactly on the same lines as in the Table Mountain Sandstone. The differences between the two series, however, are too great to allow these resemblances to puzzle anyone who has had them pointed out.

The fossils of the Witteberg beds are extremely important, as they are the same as those found in the Coal Measures in Europe and America, namely, lepidodendroid stems. The actual stems are usually *Bothrodendron*, but *Lepidodendron* does occur, as well as the roots of this forest tree, *Stigmaria.* These forms probably originated in the Southern Hemisphere, and were driven northwards on the advancing cold of the succeeding glacial epoch. When they reached the equator they were again driven north by the recurrence of genial climate, and the heat of the tropics became too much for them. A few stragglers came south again, and are found in the Karroo sediments. The *Spirophyton* is a screw-like seaweed with a very wide flange marked with sickle-shaped ribs. It occurs in Devonian and Carboniferous rocks in Europe and America. There is another species in which the flange of the screw is broken up into a number of rods which radiate screw fashion from a central axis. The root of the South African *Spirophyton* is always downwards; in other countries the seaweed apparently grew downward. *Hastimima* is a gigantic water scorpion (Eurypterid).

These three series—the Table Mountain, Bokkeveld, and Witteberg—form a fairly compact formation, the Cape Formation. At the bottom is a more or less pure quartz series, then a deep-water series, and finally a ferruginous sandstone and shale series. This threefold formation is simply a repetition of what occurred farther north in previous times, when the quartzites of the Black Reef Series were followed by the dolomite, which in turn was followed by the Pretoria Series. The conditions of the deposition of the Cape Formation can be fairly well established. The land lay to the north, the shore line in the beginning running east and west a little south of Kimberley. There was probably a southern shore line formed by the prolongation of the Madagascar ridge, and in the strait thus formed the Table Mountain Sandstone was laid down; the turbulence of the currents would explain the marked false bedding which is characteristic of the Table Mountain Sandstone throughout. Then the sea-floor sank, and over the close in-shore de-

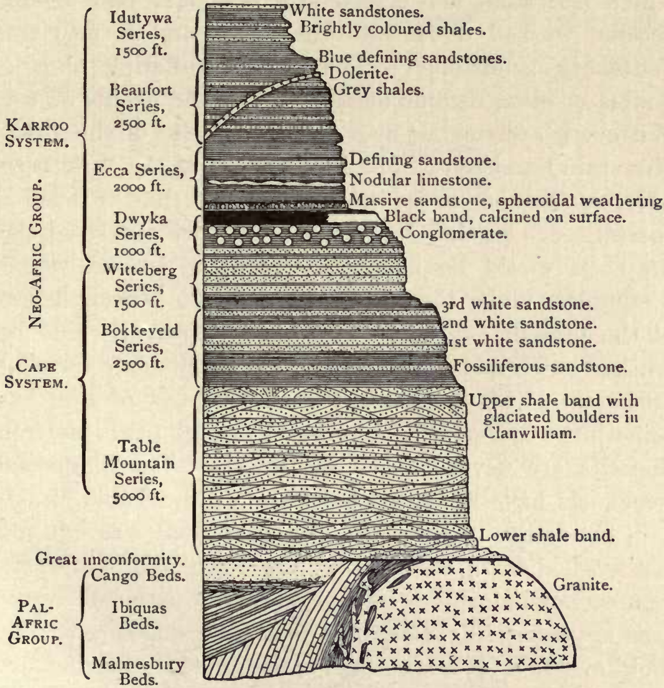


Fig. 41.—Scheme of the Strata in Cape Colony

posits were laid down the deeper-water deposits, muds, of the Bokkeveld. The shore line retreated northwards, and over the coastal plains of the continent which yielded the sands of the Table Mountain Series water now flowed, and deposits similar to the Table Mountain Sandstone were laid down. The sea bottom now rose and the shore line advanced southwards, and over the deep-water deposits of the Bokkeveld were laid down once again shallow-water sands, the Witteberg rocks. The sands then, recently formed on the strip of coast land which had sunk and which now was laid bare again, became washed down into the water and formed the Witteberg sandstones. The grains, suffering thus a double erosion, became smaller, hence the grains of the Witteberg are smaller as a rule than those of the Table Mountain Sandstone. The iron content of the Witteberg one may assume to be due to the fact that on such a coastal ledge as that from which they were derived the drainage would be imperfect, ironstone gravel would accumulate under the soil as it does in the coastal ledges at the present day, and this ironstone gravel would be washed down and incorporated in the sediments forming offshore. It may be, also, that the deposit of iron has something to do with the water being fresh, as iron deposits are never formed in the sea. The Transvaal geologists have assumed that some of the Table Mountain Sandstone of this northern coast shelf was left and not washed down, and that it now forms the Waterberg Sandstone; but this is improbable if the order of events was anything like what has just been described. The Bokkeveld Series at the base is undoubtedly marine, but there is evidence that the open ocean was being enclosed, and in the Witteberg times the deposit was laid down in a freshwater lake, for the fossils of the Witteberg are those usually found in freshwater deposits. While the Bokkeveld was thus changing from a marine to a freshwater deposit the shore was continually oscillating, and when it advanced south shore-deposits were laid down, as evidenced now by the sandstone bands. When the shore line retreated again northwards the sands became again covered with deeper-water sediments. That the shore was to the north we know from the fact that in the western province the sandstone bands are practically absent in the southern portion about Swellendam and Caledon, whereas as we go northwards into Ladysmith and Willowmore they are very conspicuous, indicating a nearer approach to the shore.

The Karroo Formation

At the base of this formation there is a thick deposit of Dwyka Conglomerate interlain between two bands of shale. Above this comes the Ecca Series, and then the Beaufort and Idutywa series. Many authors include the Stormberg Formation in the Karroo System, but there are many reasons why it is better to separate the two, the most conspicuous being that the fossils of the Karroo System form a compact group entirely different from the fossils of the Stormberg, while the rocks themselves are of quite different texture and nature. The beds of the Karroo System are characterized by a peculiar fern called *Glossopteris*, which is not found in the beds above or below.

The Dwyka Series is best described by explaining how it was formed. The Southern Hemisphere became glaciated, owing, as has been mentioned above, to the abstraction of the carbon dioxide from the atmosphere by the intense limestone formation of the lower Carboniferous rocks of Europe and America, and again by the immense coal formation of the Upper Carboniferous. The rivers ceased to flow, and instead glaciers poured blocks of ice broken off from the seaward ends by the waves into the Karroo lake. The icebergs floated over the inland lake, and on melting dropped the boulders held frozen in the ice to the bottom, where they became embedded in the mud accumulating there. The shore line ran through Prieska and the Southern Transvaal, and the actual valleys down which the glaciers flowed can still be traced and the ice-scratched pavements and roches moutonnées can be seen. North of the shore line the glaciers, which, indeed, seem to have united at one period into a continuous ice sheet, left great accumulations of morainic material when the ice finally melted, so that all Prieska and the Southern Transvaal are covered with a terrestrial till or boulder clay. South of the old shore line the Dwyka Series begins with normal shales deposited on the Witteberg, which then became more and more conglomeratic as the icebergs discharged their burdens of rubble on to the sea floor; the Dwyka Conglomerate on the south thus is a sub-aqueous till or boulder clay. The actual transition from terrestrial to sub-aqueous till may be seen in the Tanqua valley, on the west of the Karroo, where a glacier from the land ploughed over the mud and boulders formed beneath the water and caused a glaciated pavement to form on the actual till. The rocks included in the Dwyka Conglomerate as boulders are derived from all the older formations exposed in Prieska, Bechuanaland, and the Transvaal; among others one may find granite and gneiss, diabase and acid lavas, sandstones from the Kheis, Black Reef, and Waterberg Series, dolomite and jaspers from the Pretoria Series. The matrix of the Dwyka Conglomerate in the north is a bluish-grey mud which changes to yellow where the surface water has acted upon it, so that we have the blue and yellow ground very similar in appearance to the blue and yellow ground in the diamond pipes; but the presence of ice-scratched boulders at once tells one what the deposit is. In the south the matrix is harder, and weathers with a peculiar pillow structure which is very characteristic, the rounded blocks standing up like tombstones. It was behind these that the Bushmen were fond of hiding to shoot off their poisoned arrows at the unwary Boer; hence the popular name for the Dwyka Conglomerate is Bushman's Klip. The ice-scratched boulders in the south are quite as plentiful as in the north, and when the matrix has been softened a little by weathering, the surface of the Dwyka Conglomerate is identical with that of the glacial drift of England or north Europe. The Dwyka Conglomerate forms an extremely tough band which does not readily give to expansion and contraction except on the surface; hence springs are very rare in the country covered by it. The Upper Dwyka Shales are largely made up of extremely fine-grained shales which weather in peculiar starch-like fragments. Some of it is carbonaceous, and there is also sufficient pyrites in the rock to make it spontaneously ignite when water gains access to it. The fallen "reef" in the Kimberley mines has thus caught fire. Usually on the natural surface the ignition is slow and the black shale burns to a brilliant white calcined rock which forms a conspicuous white band. The pyrites, in decomposing, yields sulphur, which, combining with lime, forms gypsum, and the iron itself crumbles to powder as yellow or red ochre. Large flakes of gypsum and whole hills of ochre occur on the Upper Dwyka Shales, but they are only superficial deposits. A narrow band of flint or chert usually caps the carbonaceous portion. In the Upper Dwyka Shales there have been found in Kimberley and Calvinia a number of remains of a little reptile called *Mesosaurus*, while *Glossopteris* occurs sparingly. The Lepidodendron flora is represented by a few rare *Sigillaria* and *Lepidodendron* stems. In German Namaqualand the shell *Eurydesma* and a *Conularia* have been described from this horizon, which, if authenticated, will prove that there was a connection with the sea on this side.

An interesting area of Dwyka Conglomerate occurs south of the great Worcester-Swellendam fault, which is quite typical and which shows that the Dwyka Conglomerate was continuous once over the mountains which separate this area from the Karroo; that is to say, the southern border of the lake was to the south of the present shore line. Little patches of the Dwyka Conglomerate occur in the folds in the mountains themselves. It was once held that the Karroo Beds, with the Dwyka Conglomerate at the base, were laid down in a lake the southern borders of which were where the present coast ranges lie; but as the Karroo Beds occur to the south of the mountains it is evident that the mountains were folded up after the Karroo sediments were all deposited, and that the Dwyka Shales exposed on the flanks of the mountains are the beds deposited in the deeper central portion of the Karroo lake exposed by folding. This disposes of the theory that the carbonaceous beds of the Upper Dwyka Shales may, in the deeper portions of the Karroo, become actually coal-bearing, a theory which has been urged and on which thousands of pounds have been spent in boring for this hypothetical coal. The underlying idea, however, of this theory is not geological at all; it arose from the belief that God made all parts of the earth equally good, and that as the Karroo is so horribly awful on the surface there must be something to compensate for it beneath.

The Ecca Series.—This is a well-marked division on the south of Cape Colony but is missed out on the north. In the west, in Mordenaar's Karroo, the Ecca consists of brown sandstones, with *Glossopteris,* and grey shales. This is referred to as the Laingsburg Beds. In Prince Albert there is a succession of shales separated alternately by dark-purple sandstones weathering into irregular blocks coloured red, by limestones weathering brown, and by blue sandstones crumbling into a yellow sand. The country made of this four-phase Ecca is peculiar; there are valleys where the softer shale has crumbled and has been blown away, separated by ridges alternately red, brown, and yellow. Farther east, from Willowmore onwards, the Ecca is mostly shale with subordinate shaly sandstones marked with a pecular mottling; the prevailing colour is blue and the mottling usually takes the form of white spots, the origin of which is quite unknown. The mottling passes through all varieties of rock; even the septaria that occur somewhat plentifully are affected. A great deal of silicified wood is found in this eastern Ecca, especially south of Graaff Reinet, where the plains are covered with it. Still farther east, in the Transkei, there are thick beds of sandy clays, dark-blue in colour, weathering to a brick red; when hardened by intrusions of dolerite they form a hard black mass with a fracture like flint. These have been called the Umsikaba Beds; they gradually merge at the top into the Idutywa Beds, that is to say, the Beaufort horizon is missed out.

The Laingsburg Beds, the Four-phase Ecca, the Mottled

Ecca, and the Umsikaba Beds are contemporary *facies* of one and the same series.

At the type section through this series at the Ecca Pass, near Grahamstown, the Upper Dwyka Shales are thoroughly calcined by the oxidation of the pyrites, the heat of the reaction and the consequent expansion having been sufficient to crumble the rocks into sharp folds, whereas the rocks on either side are unaffected. Above this white calcined rock there are brittle, thinly bedded shales breaking into angular slabs, and above this a bed of mottled purple sandstone (intermediate sandstone), and above this massive blue-black sandstone showing remarkably well the spheroidal weathering. This feature is usually exhibited in igneous rocks such as dolerite, and is due to contraction after consolidation. Above the massive sandstone there are brittle shales breaking into heaps of starch-like fragments, and on the very flat dip slopes there are exhibited roots and indeterminate stems of plants. All the shales are ripple-marked and sun-cracked, and show on a small scale a kind of spheroidal weathering, such as is often exhibited in mud that has dried after deposition. The mottling in white appears sporadically. Septaria also occur, the lime usually concentrating round centres of foreign bits of black shale in the sandstones.

The Ecca Beds on the south of the mountains are exposed against the Worcester-Swellendam fault at Worcester Station. They lie next to the Malmesbury Beds, so that the fault has a throw equivalent to—

	Feet.
Part at least of the Ecca Beds	500
The whole of the Dwyka Series	500
The whole of the Witteberg Series	1,500
The whole of the Bokkeveld Series	2,500
The whole of the Table Mountain Series	5,000
And some portion of the Malmesbury Series ...	1,000
Total throw of the Worcester-Swellendam fault	11,000

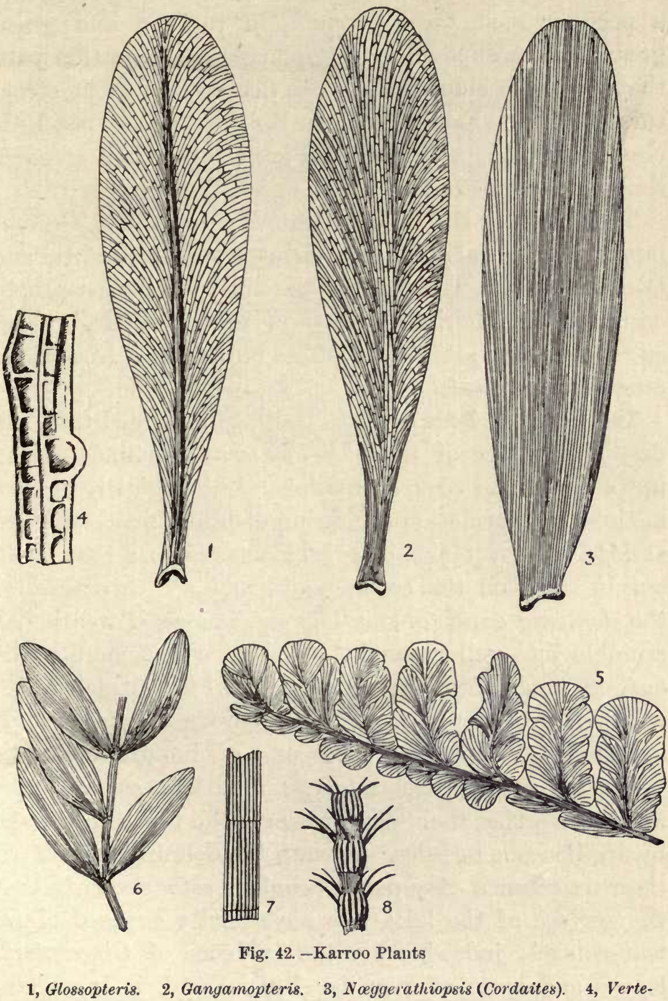


Fig. 42.—Karroo Plants

1, *Glossopteris*. 2, *Gangamopteris*. 3, *Nœggerathiopsis* (*Cordaites*). 4, *Vertebraria*, the underground stem or rhizome of *Glossopteris* and *Gangamopteris*. 5, *Neuropteridium validum*, Seward. 6, *Schizoneura gondwanensis*, *Feistmantel*. 7, Stem of *Schizoneura*. 8, *Phyllotheca indica*, Bunbury.

It was the finding of *Glossopteris*, *Gangamopteris*, and a peculiar seed, *Cardiocarpon*, in the red and green greasy shales exposed in the quarry in the station yard that gave the clue to the existence of this great structural feature. Farther east, in Robertson, the Ecca Beds rise into considerable hills, and are composed of greenish shales and sandstones.

The fossils of the Ecca Series are *Glossopteris*, *Gangamopteris*, the calamite-like stems of *Schizoneura*, and *Cardiocarpon*. The first of the Karroo reptiles proper occur on this horizon, the form being called *Archæosuchus*. There are also in places crowds of a freshwater mussel, *Palæomutela*.

The Beaufort Beds.—These beds are reckoned from the first appearance of the *Pareiasaurus* remains passing upwards in the rock succession. Lithologically it is a monotonous formation consisting of bluish shales divided at intervals by bluish or greenish sandstones that stand out in steps on the escarpments, and are thence called the *defining sandstones*. The sandstones, if weathered, crumble into yellow sands. There are also more shaly, darker sandstones, often mottled with purple, which weather with a red coat. These are the *intermediate* sandstones. Septaria and banks of impure dolomitic limestone occur, becoming less and less as one goes up in the series, their place towards the top being taken by argillaceous nodules. Beneath the defining sandstones there is often a clay-pellet conglomerate, showing that the surface of the lake was occasionally exposed above water level; indeed, from the evidence of *Glossopteris* leaves and roots at Van der Byl's Kraal, it is evident that the mud banks often existed for some considerable period, and formed islands covered with vegetation.

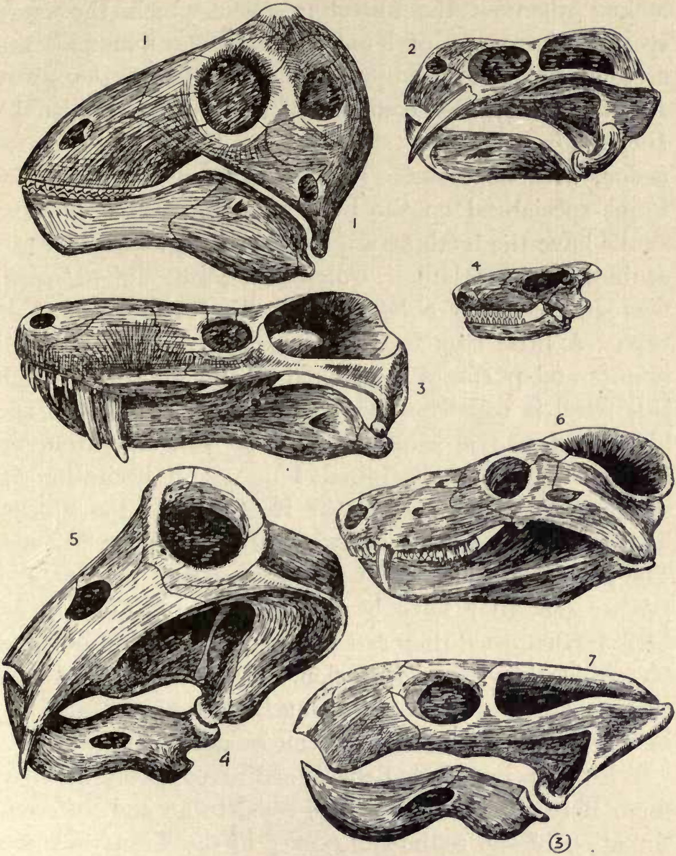


Fig. 43.—Karroo Reptiles

Dinocephalia: 1, *Delphinognathus conocephalus*, Seeley. Anomodontia: 2, *Dicynodon sp.*; 7, *Oudenodon gracilis*, Broom; 5, *Lystrosaurus M'Caigi*, Seeley. Therocephalia: 3, *Lycosuchus van der Rieti*, Broom. Theriodontia: 6, *Cynognathus crateronotus*, Seeley. Procolophonia: 4, *Procolophon trigoniceps*, Owen.

The Karroo fossils are famous for their being forms, which unite in their skeleton the characteristics of reptiles, amphibia, and mammals; they have thus been looked upon as the ancestors from which the more specialized reptiles of later ages and the mammals are descended. The most generalized type is the great *Pareiasaurus*; the commonest form, however, is the *Dicynodon*, with two tusks, and the female form, Oudenodon, with no tusks. Towards the top there are the forms specialized on the lines of mammals in that the skulls have the teeth arranged as in a dog, with incisors, canines, and molars. *Gomphognathus*, *Trirachodon*, *Cynognathus*, and a host of similar forms are of this type. A little step farther and we have what is to all intents and purposes a mammal, *Tritylodon*. Although this fossil is usually said to come from the Karroo, the history of the specimen has been lost, and from an examination of the original I have no hesitation in saying that it comes from the Red Beds of the Stormberg Formation, that is, is lower Jurassic and not Triassic. The Karroo Beds extend to the sea at East London, and farther east they have been termed the Kentani Beds. Still farther east they are not very well represented, a fact which has led to confusion. The occurrence of reptilian remains in the shales along the Umkomazan River, in Western Natal, seems to be an isolated reappearance.

With the Beaufort Beds the Karroo Beds, as they occur normally in the Karroo, come to an end. A continuation of the sediments occurs in the Transvaal, and right up in the lake district the Drummond Beds are of the same age, though they were laid down in another lake basin. The whole southern hemisphere was united in one great continent, which has been called, by Suess, Gondwanaland, because the beds are all of the type that occur in the Gondwana System in India. In India the glacial conglomerate at the base is called the Talchir

Conglomerate, in Australia the Bacchus Marsh Conglomerate, and in South America the Orleans conglomerate. The Karroo reptiles are only known from the Cape, India, and Russia; *Glossopteris*, however, all over Gondwanaland.

The Idutywa (Burghersdorp) Series.—In the reports of the Geological Survey these beds were described in 1901 as Idutywa Beds, and were again described, in 1905,

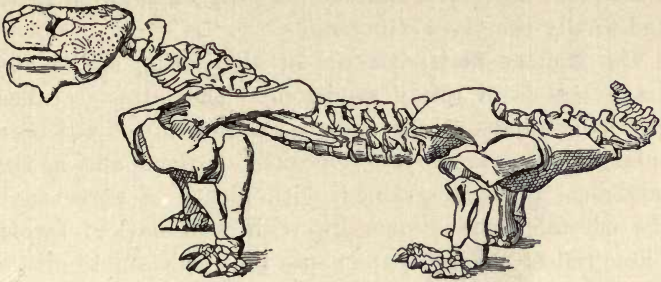


Fig. 44.—Type of Karroo Reptiles: Pareiasaurus

as Burghersdorp Beds. The series lithologically consists of white or buff sandstones, fairly loose-grained, separated by shales brightly coloured in blue or purple-red, often, however, grey, green, and mottled. The beds occur capping the highest hills of the western Karroo, and are found again in Aliwal North and the Free State, and again in Cathcart, and in the Transkei, from Idutywa eastwards.

Glossopteris still occurs as a fossil in those beds, but they form a transition series between the Karroo proper and the Stormberg Formations, and therefore contain many of the Stormberg plants. The sandstones are full of freshwater fish, *Semionotus*, *Cleithrolepis*, *Atherstonia*, and *Ceratodus*, the Australian mud fish, which is still living. The white sandstones are used in the Free State largely for building purposes, and are called *Steenpan.*

The Stormberg Formation

In this system, which is confined to the eastern portion of South Africa, there are three divisions, the lower containing the Molteno, Cyphergat, and Indwe coal seams, and called the Molteno Series, then the Red Beds, and finally the Cave Sandstone.

The Molteno Series consists of alternating shales and massive beds of gritty sandstone. The latter is called glittering sandstone, because the sand grains have been enlarged by quartz being deposited on them, and as the sandstone is coarse-grained, with plenty of pore space, the crystals have grown up with well-marked facets. These reflect the light, and cause the sandstone to glitter in the sun. Often there is a considerable amount of undecomposed felspar and mica in the sandstone, indicating the near proximity of granite, from which the sediment was derived. As the nearest granite on the north is more than 200 ml. away, it is obvious that we cannot look to that as a source of supply; therefore we can establish that the southern granite border of the original Karroo lake was not far distant. The sandstone also becomes very coarsely conglomeratic, with boulders as large as a child's head. Ironstone concretions are frequent. The coal seams mostly lie under the sandstone krantzes, and are thin and laminated with shale, showing that the vegetable matter has been transported from the place where the plants grew, that is, on the southern border of the Karroo lake, the old Madagascar ridge, now sunk beneath the waves.

The fossils of the Molteno Beds are found in the shales sometimes at the base of the sandstones, and are beauti-

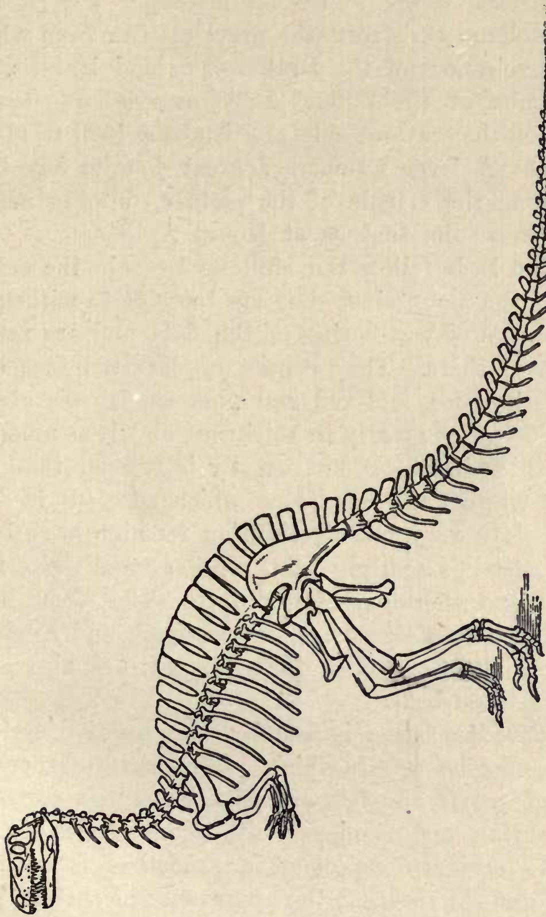


Fig. 45.—Type of the Stormberg Reptiles. Restoration of the skeleton of *Megalosaurus bucklandi* (Meyer)

fully preserved. The type fossil of the series is *Thinnfeldia*, always with bifurcating fronds, but there are a large number of associated plants which enable one to date the series as equivalent to the European Rhætic.

The Molteno Beds form the great plateau from which rise the volcanoes of the Drakensberg and Malutis, the Quathlamba of the Zulus. It is everywhere steeply scarped on the seaward side, and is about 4000 ft. above sea level. A large number of great dolerite laccolites occur along the margin of the plateau, forming mountains such as the Insiswa at Mount Ayliff.

The Red Beds follow the Molteno Beds in the actual slopes of the mountains; they are too soft to withstand the processes of weathering on the flats, and are rarely represented there. They consist of dark-red tenacious clay at the base, and red and pink sandstones above. The series varies greatly in thickness, and is as much as 800 ft. thick in places, but usually is thinner than the brilliant-white Cave Sandstone which succeeds it. In the red clays very fine dinosaurian remains have been found; these were gigantic reptiles with bird-like skeleton and enormous clawed feet. The forms have been called *Hortalotarsus*, *Massospondylus*, and *Euskelosaurus*; a little crocodile, *Notochampsa*, has also been found in these beds.

The Cave Sandstone is usually one massive bed of white sandstone 800 ft. thick. It consists of rounded grains of quartz and felspar which have been corroded on the surface and enveloped with minute scales of talc; thus the ordinary aspect of a sandstone is entirely masked and the rock has the appearance of chalk. The sandstone is not an ordinary sediment, for the fine coating of talc scales would have been soon rubbed off the sand grains if they had been dragged along the sea floor

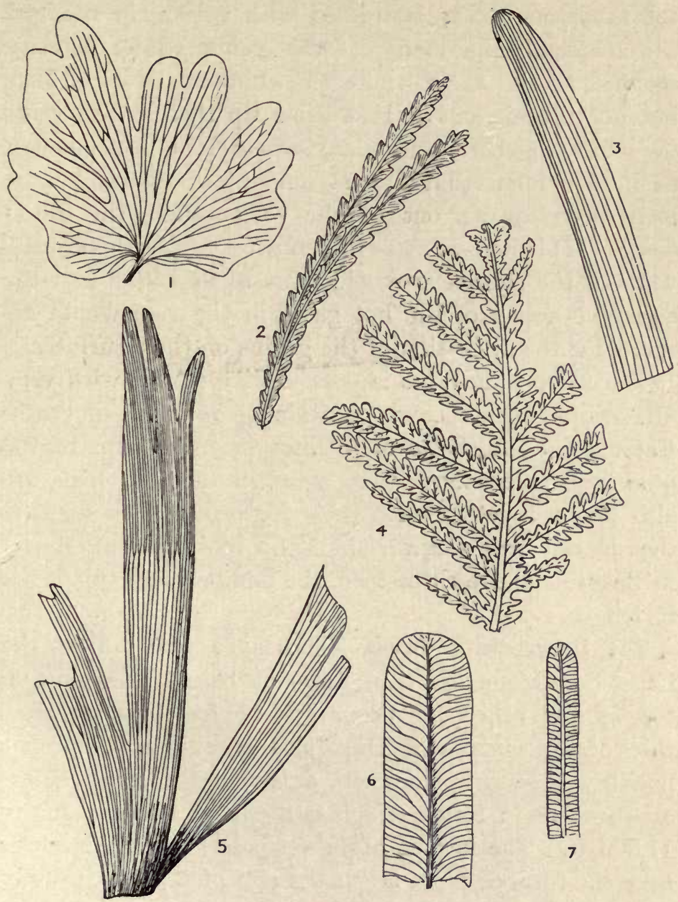


Fig. 46.—Stormberg Plants

1, *Chiropteris zeilleri*, Seward. 2, *Thinnfeldia odontopteroides*, Morris 3, *Phœnicopsis elongata*, Morris. 4, *Callipteridium stormbergense*, Seward. 5, *Baiera stormbergensis*, Seward. 6, *Tæniopteris carruthersi*, Woods. 7, *Ib.*

by currents, and the coating could not have formed after the sandstone was consolidated. The whole area where the sandstone exists is riddled with volcanic vents, and the material fills many of the vents whose activity stopped at the stage where the chimneys were drilled, but no volcanic ash or lava came up them. The vents are close together, and many are a mile in diameter, so it is evident that a vast amount of material must have been thrown out by the volcanoes in the initial stages. This non-volcanic material torn from the granite walls of the chimneys would issue as fine sand, and the corrosive action of the hot gases in the vent would account for the alteration of the grains on their surfaces.

The Cave Sandstone is occasionally parted with very fine-grained shale bands containing remains of fresh-water pond life, *Estheria*. Dinosaurian remains of the same nature as those that occur in the Red Beds are also found, together with their footprints, showing that the deposit was terrestrial. The footprints at Morija in Basutoland are three-toed, the middle toe being 11 in. in length.

The Drakensberg Lavas.—The lavas that follow the Cave Sandstone are thin flows of basalt piled one on top of the other for thousands of feet; the greatest thickness measured at Ongeluk's Nek is 5000 ft., but possibly a greater thickness exists in the great Mont-aux-Sources in Natal, which is a cliff of basalt rising to 11,000 ft. The lava is often vesicular, and the vesicles take the form of pipes about the size of a pencil, usually filled in with agate or various zeolites, or again calcite and chlorite.

The vents from which these lavas have been extruded are crowded together along a broad area, probably a system of fissures which continues the Great Rift Valley of the north, and which bends round and reappears in the rift valleys of the west of Cape Colony. The vents sometimes run together as an open fissure out of which gushed lava. Many of the vents are exposed in the seaward side of the range, showing that the greater portion of the original pile of lavas, including the central mass, has been denuded away. This is due to the fact that the lavas were piled up across the rivers that originally flowed from the main watershed to the Indian Ocean. The rivers on the land side of the volcanoes were thus turned back, collected into the Orange River, and the waters were made to flow across the whole breadth of Africa to the Atlantic. The rivers on the seaward side, on the other hand, had only a short course to the sea and therefore having very great fall had enormously greater erosive power than the rivers in the land side of the volcanic range with their extended course, barred in addition by the granite of Augrabies Falls. Hence the crest of the volcanic range has crept away from the sea.

It is not usual for volcanoes to emit lavas entirely without ash. The Hawaiian volcanoes do so; Mauna Loa being a pile of lavas 30,000 ft. high measured from the sea floor. There is remarkably little ash in the volcanoes of the Drakensberg; a little is preserved in those vents which never reached the mature stage of lava emission, but beds of ash occur very sparingly. Some of the vents may still be seen with the lava issuing from the opening just as it formed in Jurassic times.

The Stormberg Formation is well represented in Australia, where it follows the marine Permo-carboniferous with the Coal Measures which there take the place of the South African freshwater Karroo Beds.

The Uitenhage Formation

While the Stormberg Formation was being laid down, and the volcanoes of the eastern part of Cape Colony were active, the western portion was being subjected to violent agitation from the thrusting in of the Karroo dolerite, and the Cape folded mountains were being formed. When the mountains were first thrust up the more superficial rocks were structurally weak from the bending, and readily gave to the action of weathering and erosion. The whole continent had risen 2000 ft. after the last beds in the central Karroo had been laid down and the first peneplain in these parts was already cut. On this peneplain, now elevated 4000 ft. above sea level, the debris from the mountains was deposited. As the torrents rushed from the mountains they carried enormous volumes of gravel with them; but the waters coming to the plain beneath lost their velocity and their carrying capacity, therefore the boulders were left lying at the foot of the hills. These boulder beds are the **Enon Conglomerate**, red below and white above, and 2000 ft. in thickness. The land was sinking again; part of the Enon Conglomerate, at Knysna for instance, fell beneath the sea and had marine organisms included in it. The whole continent was now once more nearly awash, and only the mountains towered above the plains. The lessened height of the mountains and the harder rocks exposed caused the succeeding deposits forming on their flanks to be only sands and muds. These were laid down on the plains, over which there were tracts of marsh land, fresh-water pools and sand dunes, among which dinosaurs scrambled and left their bones. Cycads and ferns, much like the present-day forms, grew, and the remains are

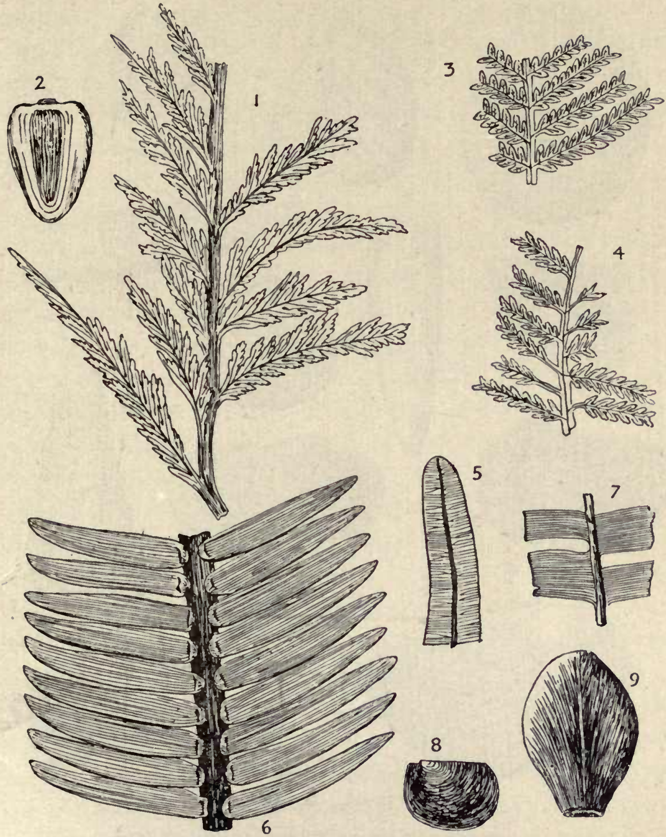


Fig. 47.—Uitenhage (Wealden) Fossils

1, *Onychiopsis mantelli*, Brongniart. 2, Scale of cone of *Araucarites rogersi*, Seward. 3, *Cladophlebis browniana*, Dunker. 4, *Sphenopteris fittoni*, Seward. 5, *Tæniopteris sp.* (Herbertsdale). 6, *Zamites recta*, Tate. 7, *Nilssonia tatei*, Seward. 8, *Estheria anomala*, Jones. 9, *Cycadolepis jenkinsiana*, Tate.

found in the deposits. This terrestrial and freshwater deposit is the **Wood Beds.** Now the continent sank definitely under the sea, and the Wood Bed was covered

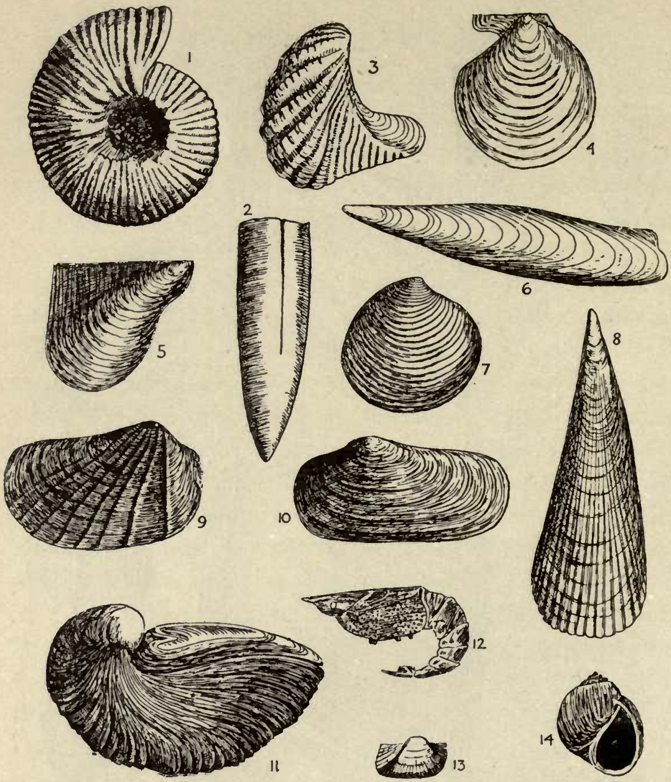


Fig. 48.—Uitenhage Marine Fossils

Cephalopoda: 1, *Holcostephanus rogersi*, Kitchin; 2, *Belemnites africanus*, Tate. Lamellibranchiata: 3, *Trigonia ventricosa*, Krauss; 4, *Pecten cottaldinus*, d'Orbigny; 5, *Perna atherstonei*, Sharpe; 6, *Gervillia dentata*, Krauss; 7, *Astarte herzogi*, Goldfuss; 8, *Pinna sharpei*, Tate; 9, *Pholadomya dominicalis*, Sharpe; 10, *Pleuromya baini*, Sharpe; 11, *Exogya imbricata*, Krauss; 13, *Arca jonesi*, Tate. Gasteropoda: 14, *Natica uitenhagensis*, Kitchin. Crustacea: 12, *Tancredia schwarzi*, Kitchin.

with clays and shelly limestones of the **Sunday's River Marine Beds**: on the eastern side of the continent there are no contemporary beds, all traces of them having been washed away by denudation. Now the continent rose, and in doing so the rift valleys caused slips of the earth's crust to sink into fault pits arranged in linear series. The mountains, towering once more, caused great precipitation; rivers coursed over the plains, scouring off all the newly formed and still loosely compacted shales, sands, and gravels, and all would have disappeared had not some of them been dropped into the fault pits, where the rims of harder rocks protected them from being carried away. It is in these fault pits alone, therefore, that we now find the Uitenhage Beds. They formed originally a continuous deposit certainly from Uitenhage to Worcester, a distance of 200 ml., but they probably extended all over the east, and the Emboyti Conglomerates on the Pondoland coast east of St. John's are probably a remnant. They certainly were formed in the north of the mountain ranges, filling in the space between the folded mountains and the escarpment of the Nieuwveld, Cambdeboo, and other mountains, which had already been cut, but all trace of these inland Uitenhage Beds has disappeared.

The Uitenhage Beds are lower Cretaceous; the fresh-water fossils are Wealden, and the marine Neocomian, the two terms indicating different *facies* of contemporary beds. The most interesting fossils in the marine series are the Ammonites and Trigonias, which occur very plentifully; one *Plesiosaurus* has been discovered, at Redhouse.

The Pondoland Formation

These Upper Cretaceous beds have been also called the Umzamba Beds and the Izinhluzabalungu Beds. They occur just on the Cape Colony side of the Umtamvuna

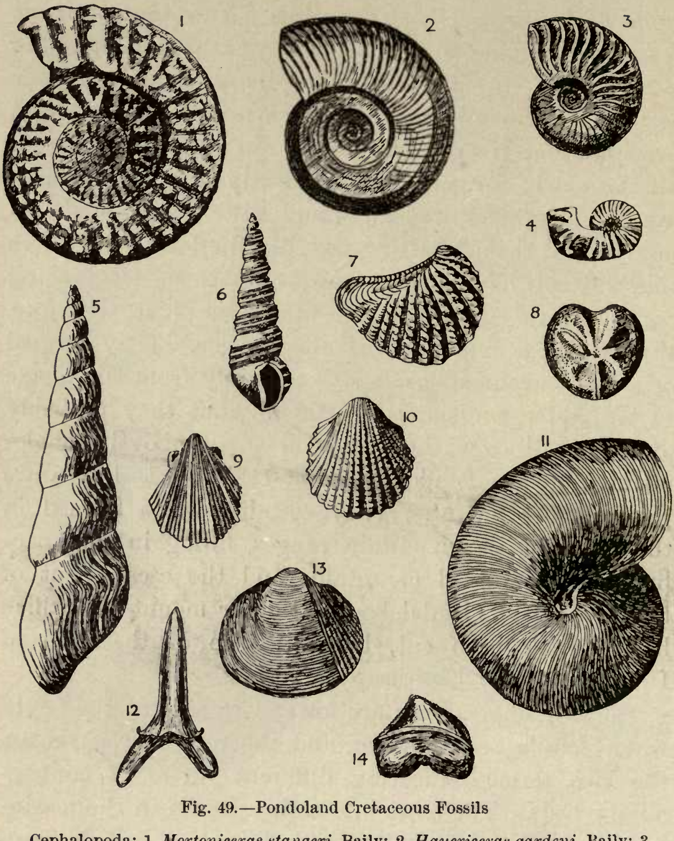


Fig. 49.—Pondoland Cretaceous Fossils

Cephalopoda: 1, *Mortoniceras stangeri*, Baily; 2, *Hauericeras gardeni*, Baily; 3, *Schlœnbachia umbolazi*, Baily; 4, *Scaphites sp.*; 11, *Nautilus sp.* Gasteropoda: 5, *Pseudomelania sutherlandi*, Baily; 6, *Turritella bonei*, Baily. Lamellibranchiata: 7, *Trigonia elegans*, Baily; 10, *Cardium denticulatum*, Baily; 9, *Pecten quinquecostatus*, Sowerby; 13, *Protocardia hillana*, Sowerby. Echinoidea: 8, *Hemiaster forbesi*, Baily. Pisces: 12, *Odontaspois cuspidata*, Agassiz; 14, *Corax pristodontus*, Agassiz.

River, in a thin slip faulted against the Table Mountain Sandstone; they then are picked up again in Zululand, and continue northwards in the sunken country east of the great fault which comes from Lake Nyasa, down the Shiré River almost in a straight line to Delagoa Bay and Durban, and from here truncates the eastern portion of Cape Colony, and runs out to sea along the edge of the Agulhas plateau. The deposit consists of sandy and clayey limestones, with banks of shell limestone; it is very fossiliferous, and has afforded magnificent specimens of Ammonites, Nautilus, Trigonias, and other Cretaceous mollusca, besides sharks' teeth, bones of turtles, and the skeleton of the great snake-like lizard, *Mosasaurus*. Similar beds occur in Southern India, Japan, and Vancouver.

The Alexandria Formation

From this time onwards the land rose by fits and starts, and along the coast there are shelves cut at varying levels; from 1500 ft. downwards the shelves are covered in the Port Elizabeth, Alexandria, Bathurst, Peddie, and East London divisions by a beach deposit, sometimes calcareous shell sand, sometimes beach boulders. The fossils are uppermost Cretaceous and Tertiary, and among the larger shells of *Pectunculus*, *Perna*, *Turritella*, there are at East London crowds of corals and Polyzoa. At Sandflats there is foraminiferal limestone. The Alexandria Formation is peculiar, in that the deposits on the 1500-ft. plateau are undoubtedly Danian or uppermost Cretaceous. The next shelf was later, but the deposit and the fossils in it are the same as on the last, and so on down to sea level. Now the deposit on the lowest shelf is evidently very much more recent than the Danian deposits at Sandflats or East London, yet the fossils in them all are the same; the shells are smaller, perhaps, but otherwise identical. So we have the case of a continuous deposit one end of which is Cretaceous and the other end Eocene, Oligocene, Miocene, Pliocene, or even Recent.

The deposit is often quite chalky, and forms conspicuous chalk hills in Alexandria. When it weathers, the calcareous matter dissolves, leaving a fine residue of clay stained a brick red with iron.

In other parts to the east and west contemporaneous deposits at the same elevations consist of masses of silicified gravel, ironstone gravel, and cemented river gravel, showing that at the time that the central area was beneath the sea these portions were dry land. The hilltops covered with these deposits are always level, and the hard cemented rock at the summits presents often fantastic forms. In the Ruggens of Caledon, a peneplain of Bokkeveld Beds deeply cut into by a maze of gorges, the soft slates weathering beneath the hard caps has left them standing with precipitous sides like walls of castles. In Kentani there is a conspicuous cap of these surface quartzites at Quintani Hill.

Recent Deposits

These include the estuarine deposits lying in the sunken valleys of the rivers along the coast. They are mostly composed of greenish sands and clays full of shells belonging to recent species and foraminifera. Above these, at Mossel Bay, there is a still more recent deposit, with shells and chipped flints of human manufacture. These are different from the usual Strandlooper and Bushman flints, and have much in common with the chipped flints associated with the bones of rhinoceros, lion, antelopes, owls, mice, &c., which are found in the caves in the lead and zinc carbonates at Broken Hill, Rhodesia.

The sand dunes are of several ages, the older series forming consolidated masses of limestone of great extent in Saldanha Bay, Bredasdorp, Riversdale, Knysna, and at the Bluff at Durban. The dunes are 600 ft. high, and from Cape Agulhas to the Gouritz River form a strip from 10 to 15 ml. broad for a distance of 120 ml.

Some of the dunes are very old, and the shell sand has broken down to a continuous chalky deposit, in which bones of extinct types of horse, and of great antelopes, elephants, rhinoceros, and so forth, which now live far to the north, are embedded. More recent dunes occur on the seaward side, and over the flat surf-cut shelf which separates the Cape peninsula from the mainland.

TRANSVAAL-BECHUANALAND

This area is a very much older one than the Cape area. On all sides there are present the gneisses, schists, and extremely ancient slates with intrusive granite, which we called the Malmesbury Beds in the previous section. Lying folded upon these are series of less metamorphosed sediments called the Witwatersrand System in the Transvaal and the Kheis System in the west. Upon these again lies a threefold system, the Transvaal System, very little disturbed; and again upon this comes the Waterberg System. All these are unfossiliferous, and are included in the Azoic. The last two systems, the Transvaal and Waterberg, are characterized by vast outpourings of lava, and when the Waterberg Beds had been hardened into sediments an

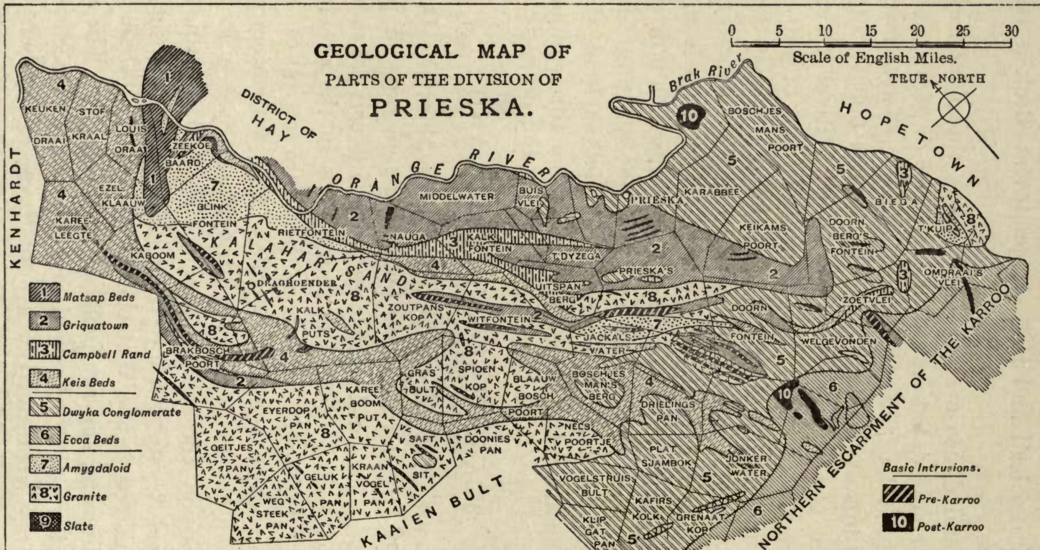


Fig. 50.—The shore line of the old Permian continent followed the northern limit of the Dwyka conglomerate. The glaciers came down from the north and the hills of Griquatown and Kheis beds bounded the valleys then as they do now. Beautiful glaciated pavements are to be seen on Jackal's Water and Boshjesman's Berg.

enormous residual mass of molten matter forced its way upwards, but failed to pierce the Waterberg sediments. Instead, it lifted them and swelled out as an enormous laccolite between them and the underlying rocks; thus was formed the Bushveld laccolite, 250 ml. in breadth. This part of the continent now became dry land, and contributed sediments which went to form the Table Mountain Sandstone and succeeding beds in the south. At the beginning of Karroo times the land was glaciated, and terrestrial boulder clay lies over a large portion of the southern and western edge of the area. In the Transvaal the Karroo lake transgressed the southern portion of the area, and formed a shallow, marshy tract surrounded by dense forests, from which good coal seams were formed. The last event of the history is the fracturing of the plateau by the southern extension of the Great Rift System, which crept northwards in ever-increasing intensity till it expanded in the gigantic rifts constituting the Red Sea and Gulf of Aden in quite recent times. The rift cut off the Transvaal on the west, and along the rift broke out the volcanoes that formed the Lebombo range. On the east side of this are the low-lying plains of Portuguese East Africa, covered with Upper Cretaceous deposits; the Lebombo lavas are of the same age as the Drakensberg lavas. The centre of the Bushveld laccolite was also affected by the fracturing, and after a pouring forth of dust torn from the chimneys, which formed again a repetition of the Cave Sandstone, the lavas followed and spread out as a strip of amygdaloidal rock.

Pal-Afric Group

The Swaziland (Namaqualand) Formation

This consists of gneisses and crystalline schists and unaltered sediments above, called the Moodies Series in the Transvaal, Kraaipan Series in Bechuanaland. The older name for the last was the Barberton Series; it consists of clay slates, quartzites with magnetic bands (calico rock), passing into phyllites and mica schists. Into this is intruded granite, which forms a continuous mass coming from Zululand, through Swaziland, and up along the Eastern Transvaal, through the Zoutpansberg to Rhodesia, and thence southwards through Bechuanaland to Namaqualand. Three bosses of granite occur south of Pretoria, which are important, as it is between them that the Witwatersrand Beds occur.

The most noteworthy areas in this system are: Swaziland, with the tin and monazite fields of Embabaan, and Barberton with the gold mines. Both lie between the precipitous escarpment of the Transvaal Drakensberg mountains and the Lebombo mountains on the east.

The Witwatersrand Formation

The Witwatersrand System is divided into a lower division, characterized by hæmatite slates separated by quartzite bands, and an upper, consisting mostly of quartzites with many bands of conglomerate containing gold.

The Lower Witwatersrand Beds commence with a very thick band of quartzites lying upon the granite, called the Orange Grove Quartzite, 1400 ft. thick. The escarpment of this quartzite faces north and forms the picturesque hill which runs north of Johannesburg. Follow-

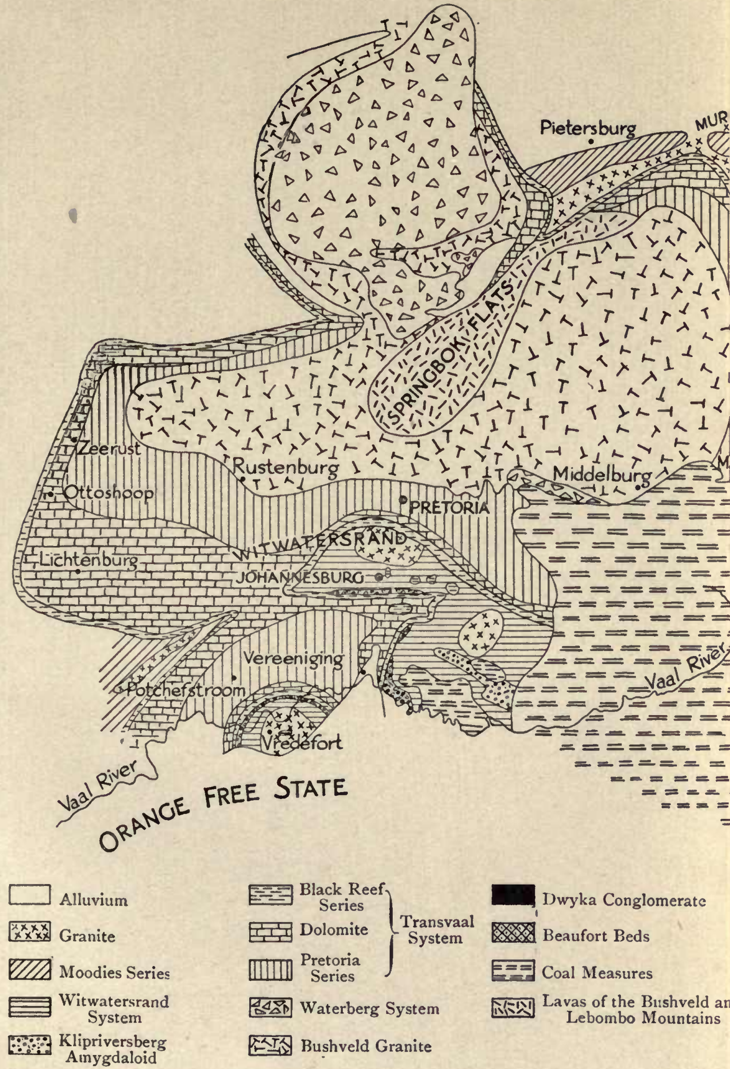
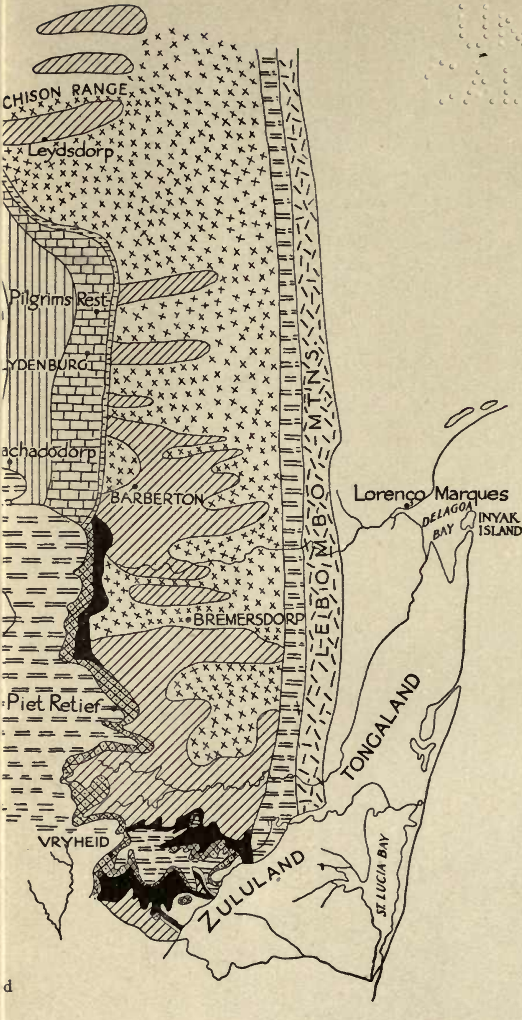


Fig. 51.—Sketch Map of the Transvaal based on G. A. F



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Molengraaff's Map

ing this are deep-red ferruginous slates 4000 ft. thick, in the middle of which is a conspicuously contorted bed made of hard ferruginous quartzites and crystalline iron ore. Above these comes a further band of quartzite, the Hospital Hill Quartzite, 1400 ft. thick, and above this the Government Reef Series, also composed of deep-red ferruginous slates, with three bands of quartz pebbles, the Coronation Reef, the Government Reef Leader, and the Government Reef. These and the final bed of soft red slates, the "Red Bar", are some 6000 ft. thick. On the Red Bar rest the **Upper Witwatersrand Beds,** some 8000 ft. of quartzites with banket reefs. At the base are the Main Reef Series, consisting of usually four or five beds of banket, separated by quartzite; the North Reef and the Main Reef are low-grade ore, but above the last is the Main Reef Leader, which is the chief source of the gold on the Rand. Its thickness varies from 6 in. to as many feet, and is very variable, sometimes running with the Main Reef, at others separated by several feet of quartzite. The middle Reef and South Reef are low-grade bankets. Following the Main Reef there are some 1500 ft. of quartzite, and then comes a large number of small pebble reefs, called the Bird and Livingstone Series. Then follow some 1200 ft. of quartzites and slates with the Kimberley Reef Series on top. This last series consists of over a hundred bands of pebbles arranged in parallel position in quartzite, the whole running to some 1800 ft. This whole system of Reefs (see fig. 52 at p. 94) runs for some 40 ml. east and west of Johannesburg, and from it more than 30 million sterling is extracted in a year. The beds dip steeply at the surface to the south, and in the deeper mines they flatten out and are supposed to come up again in a simple syncline on the south side of the basin, on the north of the granite bosses at Heidelberg and Parys, in the Orange Free State. There are, however, evidences of great thrusting and faulting in the northern area, which suggest that the stratigraphy is by no means so simple as would at first sight appear. Along these thrust faults there are dykes of diabase which also follow along the beds and may possibly be contemporaneous igneous sheets. Some of the dykes are quartz-porphyries belonging to the granite series. Farther east in the Klerksdorp area the Witwatersrand Beds again are found on the inside of the Archæan inlier, between it and the Parys granite. This is significant, and taken in conjunction with the repeated recurrence of similar conglomerates throughout the thickness of the Witwatersrand Beds, it suggests that the Witwatersrand bankets are one and the same series folded upon themselves.

The gold in the bankets has formed the subject of a long controversy. It has been thought to be secondary in origin, that is, has come up along the conglomerates while they were still loosely aggregated, in solution from some deep-seated source of supply. The simplest theory, however, is that the banket is ordinary river gravel which had gold deposited in it as placer gold; then, when the rocks were tilted and compressed, water circulating through the rock averaged the whole by abstracting from the rich patches and depositing the gold in the poorer ones.

The banket on the surface, when it was first discovered by Struben in 1880, was thought to be merely surface gravel; the free-milling ore ran to an ounce to the ton, but this richness was soon dropped as the reef was sunk on, and when the sulphide ore was reached the average came down to 12 dwt. The average of the Rand varies from month to month, according to the amount of the low-grade ore which is passed through the mills.

The Kheis Formation

The Kheis Formation occupies stratigraphically much the same position as the Witwatersrand System. It forms a great range of hills from west of Prieska to Uppington and northwards into Bechuanaland, where it has not yet been followed. It consists of—

Kheis System.	Wilgenhout Drift Series	Green lavas and sediments of volcanic origin.
	Kaaien Series	White quartzites and quartz schists.
	Marydale Series ...	Ferruginous quartzites, slates, and limestones.

The beds are intensely folded and metamorphosed, and to the west the bottom only of steep synclines remain as isolated outliers of the system. The granite that is found traversing the beds may have been squeezed in during the folding, that is, was older than the sedimentary beds, or it may have intruded the Kheis Beds subsequently, though on the latter view it is hard to see what supported the Kheis Beds before the granite came up.

The Koras Series is an uncorrelated series of coarse conglomerate and lavas which occurs along the Orange River from Groot Drink to Koras. The basal conglomerates consist of boulders of mica schist and quartzite in an arkose matrix, the boulders running to 18 in. diameter. Above these come quartz-porphyries and basalts and on top red sandstones and conglomerates, like the Waterberg Sandstone.

The Vaal (Ventersdorp) Formation

This is a most unsatisfactory system, consisting of sediments and lavas mixed up in a way that it is impossible to describe them adequately in a short résumé. The

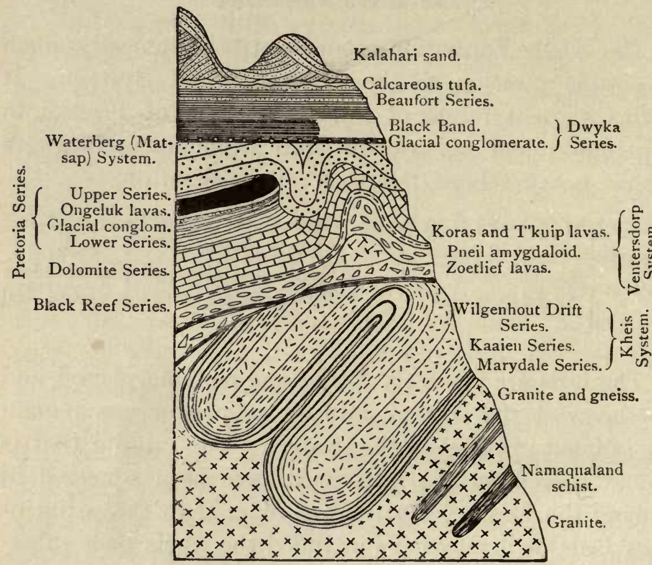

Fig. 53.—Scheme of the Pal-Afric Strata in the north of the Colony with the thin covering of Karroo Sediments and Kalahari Sand markedly false-bedded

original name was Pniel Rocks, given by Stow in 1873, which was used for the amygdaloidal melaphyres found along the Orange River in the vicinity of the diamond diggings. This character is maintained in several occurrences in Prieska and also on the Rand, where the Klipriversberg Amygdaloid forms a range of hills to the south. In Kimberley, where the rock shafts of the mines penetrated the melaphyre at about 700 ft., a quartzite was encountered which was followed down to 1528 ft., then came a diabase sheet, then rhyolite, followed by quartzite, again with a basal conglomerate. The diabase and quartzite is the Pniel Series, and the rhyolite and quartzite are called the Zoetlief Series. There is an intermediate group in Prieska called the T'Kuip Series, which consists of arkoses, limestones, and cherts with intercalated basic lavas. On the Rand, below the Klipriversberg Amygdaloid, there is also a sedimentary series, the Elsberg Beds, usually classed with the banket series, but which is clearly derivative from the Witwatersrand Beds, that is, unconformable upon them. At Langerman's Kop, on the east of Johannesburg, the same beds occur, and these show that bits of the quartzites have been broken off, rounded, and included in the sandy matrix of the Elsberg Beds. The sand grains are splintery, like those found in glacial deposits, a feature also noticeable in the conglomerate at 2230 ft. in the Kimberley rock shaft. In the south-west of the Transvaal enormous areas are covered with these boulder beds. When weathered, the conglomerate looks like the Enon Conglomerate of the Cape, but the pebbles are of far greater variety, including granite, slate, diabase, and quartzite among other rocks.

The Transvaal Formation

The Transvaal System is the most widely distributed and the most typical system of this area. On the east it overlies the Swaziland Beds that occur in the low country about Barberton and Swaziland, and forms the magnificent escarpment of the Drakensberg. From here it surrounds the great Bushveld laccolite, dipping always inwards towards it and, according to one view, giving to the outward edge lime, magnesia, and iron from the dolomites and ferruginous rocks, sufficient to convert the originally acid granite into a basic gabbro. Crossing over into Bechuanaland, the system is found prominently developed on the escarpment of the Kaap Plateau west of the Kimberley-Vryburg railway line. Thence it spreads out as a great flat plateau, gently undulated at first and then more intensely folded till it comes to the hills of Kheis quartzites in Prieska, where the system is lost. Possibly the Kheis Beds are the Transvaal Beds altered by still more violent crushing. We pick up the system again in German Namaqualand, where it forms several isolated outcrops near the coast, and is met with finally at Otawi. The system thus stretches, or stretched at one time, right across the Continent, so that it forms a belt of sediments forming off a northern shore, similarly to the subsequently deposited Cape Formation, which it closely resembles, similarity of conditions producing similarity in sediments.

The Black Reef Series lies at the base of the system. It is so called from a band of gold-bearing conglomerate (banket) which is found near the base, which, being full of pyrites, weathers with a black iron-stained surface. The gold is patchy, and though in places exceedingly rich, the banket is not exploited like the more steadily yielding Main Reef Leader. The quartzite of hardened sandstone, of which the most of the series is composed, is extraordinarily like the Table Mountain Sandstone in texture, tint, and mode of weathering, On the north of the Drakensberg escarpment the series is some thousand feet thick, but elsewhere it dwindles down to as little as a few feet only.

The Dolomite (Campbell Rand) Series lies above the

Black Reef Series. It is a magnesian limestone, rather than a dolomite, which is as much as 5000 ft. thick in places. It has received many local names, such as Malmani Dolomite, Ngami Dolomite, and Otawi Dolomite, but the only one recognized now is that given to it by Stow, Campbell Rand Dolomite, and this term is restricted to the western outcrops. It weathers with a peculiar wrinkled brown coat, due to the insolubility of the manganese contained in the rock, which is left behind when the lime and magnesia pass out in solution; this brown coat gives it the local name of Olifant's Klip, Elephant's rock. Intercalated in the dolomite there are frequent beds of chert, often peculiarly aggregated as if of organic origin, but so far no recognizable fossils have been obtained. The chert bands become ferruginous towards the top. There are many peculiar features, due to the easy solubility of dolomite, such as underground rivers. The joints down which the water travels to supply the rivers beneath often become widened and funnel-shaped at the surface; thence arises what is known as a *swallow hole*, or *wondergat*, as it is called locally, that is, a circular pool of water in the limestone. In the Kaap plateau, which is composed of horizontal beds of limestone of great thickness, this tendency of all the water to disappear underground leads to the surface being waterless; such a country is called a *karst land*, from the name given to it in the typical locality on the north-east of the Adriatic in Bosnia and Herzegovina. The underground rivers often emerge as fine springs, as at Kuruman, and these are called *dolinen*. Great masses of calcareous tufa are deposited at the foot of the escarpment of the Kaap plateau by the escape of the dolinen and the evaporation of the water. The joints, widened by solution, become filled with secondary minerals, of which galena is the commonest, and a vein so formed is technically called a gash vein, though the term is frequently misapplied. Galena occurs in Prieska and in the Transvaal, and frequently carries silver. At Malmani in the west, and at Pilgrim's Rest in the east of the Transvaal, the gash veins are filled in with brecciated quartz, with limestone cement, or sometimes with pure quartz; the veins are either horizontal or vertical, and contain gold and copper.

The Pretoria Series.—The Pretoria Series, as typically developed round Pretoria, consists of a great band of shales and quartzites overlying the dolomite. There are three quartzites, known, from below upwards, as the Timeball, Daspoort, and Megaliesberg Quartzites, averaging some thousand feet in thickness, though the Megaliesberg is usually the thickest and the Daspoort the thinnest of the three. These are separated by shales, which vary from normal blue shales and flagstones to actual hæmatite shales like the lower Witwatersrand shales, with which they were originally classed. The quartzites are usually sandstones hardened by secondary silica; but these again become ferruginous.

All round Pretoria the series has been invaded by innumerable dykes of dolerite, altered by time to diabase, and there are also some contemporaneous igneous sheets. The metamorphism produced by the diabase is extraordinary. Three types are recognized:

(*a*) The Longsight type: True contact rocks with biotite, staurolite, andalusite, and cordierite crystallized in the slates.

(*b*) The Grootboek type: Hornstones, entirely recrystallized, with biotite and cordierite forming a cement.

(*c*) Malips River type: Crystalline schists, in which the alteration has gone on both by contact and pressure metamorphism.

In the west, in Bechuanaland and Prieska, the series is more extensive and the rocks are more ferruginous. It has been called the Griquatown Series, but the term is no longer necessary. Beginning at the southernmost point of the Doornbergen, the rocks are blue-black slates and quartzites; but as one passes northwards to Prieska's Poort the character of the rocks changes; the slates turn to red, brown, and yellow jaspers, and the quartzites become white. Farther north, at the Orange River, again, the rocks become less altered, and blue-black slates once more appear; but north of this again the banded jaspers occur and continue into the Kalahari. The typical mineral of this formation is crocidolite or blue asbestos, which forms in crevices in the blue-black slates, the fibres extending from side to side of the cracks. When the country rock changes to jasper the crocidolite also alters, and changes to a beautiful honey-brown silky fibrous mass made up of quartz fibres coloured with limonite. It is really a pseudomorph of silica after crocidolite, and its technical name is tiger-eye quartz, though commercially it is known as crocidolite. A further alteration may take place when the tiger eye changes to a red variety as all the iron becomes leached out and a simple mass of white fibrous quartz is left. Frequently the crocidolite, instead of crystallizing out as fibres ranged parallel to one another, forms a felted mass of fibres; the stone thus made up is a lustrous blue-black hard mass, taking a very fine polish and being practically a blue jade. Deep-green crystals of grunerite, silicate of iron, also form from the blue-black shales, and differ chemically from crocidolite by the absence of soda. Near the top of the lower part of the series, and just below the lavas, there is a band of glacial conglomerate. It is precisely similar to the Dwyka Conglomerate in structure, though the matrix has been altered to a flinty red jasper, and the included boulders, when they can be made to break away from the matrix, show unmistakable glacial striations and facets.

Above the lower sub-series there is a great development of lavas, breccias, fine-grained tuffs, and a few intercalated layers of brilliant red jaspers. These are the Ongeluk lavas. The lavas are compact, blue-green rocks in which no crystalline structure can be seen, and are probably melaphyres altered from unstable basalts.

Above the lavas, on the west, there is a series of brown, red, and black magnetic cherty beds with a thin bed of limestone and some phyllites. These are classed as the Upper Pretoria Beds.

In the flat surface of the Kaap plateau there are long ridges of a breccia formed of blocks of Pretoria jaspers and magnetite quartzites called the Blink-Klip breccia. The history of these is peculiar. Before the Pretoria Beds were cleared away from off the limestone by denudation the water sank in, and, reaching the limestone beneath, hollowed out tunnels just below the jaspers. In course of time the tunnel became too weak to bear the load, and the jaspers fell into the tunnel of the underground stream. A similar thing happens when morainic material falls through into the channel of a sub-glacial stream, owing to the ice on top becoming too weak to sustain the weight of stones.

Veins of ore occur in this formation. The best known are the silver-lead ores of Willows Silver Mine and the

Transvaal Silver Mine. Cobalt ores occur at Balmoral, on the Middleburg line.

The Waterberg System

This system consists of a single series divided into an upper sedimentary portion and a lower volcanic portion. The lower division consists of felsites with interstratified shales and is not present in the west of the area. The upper division begins with a basal conglomerate with fragments of banded and cherty rocks which are undoubtedly derived from the Pretoria Beds, and prove the unconformity between the Waterberg and Transvaal Systems. The sandstones and shales that follow are always stained red or a reddish buff; there is never any doubt about a Waterberg rock, owing to the peculiar tint. The formation is similar to the Torridonian of Scotland, but the localities are too far apart for lithological correlation to be of any value. In the extreme west the Waterberg is probably represented by the arkoses in Namaqualand resting on the granite. In the east the beds are continued in the Palæozoic sandstones of Natal, which should rightly end north of Durban. The sandstones south of Durban belong to the Table Mountain Series, but there is much confusion in regard to this point. In the north round Nyasa and Tanganyika the Waterberg is again met with as the "Old African Sandstones" and Mafingi System.

The reasons why the Waterberg Sandstone cannot be the same as the Table Mountain Sandstone, apart from their totally different texture and colour, are that as the Dwyka Conglomerate rests unconformably on the eroded surface of the highly compacted, partially metamorphosed Waterberg Sandstone, there must have been a vast time interval between the deposition of the two sediments. In the south the Dwyka Conglomerate is separated from the Table Mountain Sandstone by the Bokkeveld and Witteberg, which represent in Europe the whole of the Devonian and Carboniferous times. This, however, is not sufficient time to account for the Dwyka Conglomerate resting on the Waterberg on the north, for the Waterberg would have had to be deeply buried for the compacting and metamorphism to go on. It would have had to be subjected to mountain-building forces, to be wrinkled up into the folds it now exhibits; the overlying strata would have had to be removed, and only then could the glaciers have flowed over the floor of altered Waterberg Sandstone, and carried boulders down into the till. As a matter of fact, similar boulders of Waterberg Sandstone are found in the Table Mountain Sandstone in Table Mountain.

Neo-Afric Group

The Karroo Formation

The Karroo Beds of the Transvaal begin with the **Dwyka Conglomerate**, which is found over the south-east of the province covering the Waterberg and Dolomite Series. The underlying beds are often beautifully striated, as at Balmoral. Farther east, in the Vryheid district, the granite and schists of the Swaziland Beds are striated. The whole of the Dwyka Conglomerate in the Transvaal, and in Natal also, is a terrestrial moraine, and hence these are neither the lower nor the upper shales that are found in the south of the Cape Colony. At Vereeniging the conglomerate is penetrated by roots of plants which went to form the coal, and hence there is an unconformity between the Dwyka and the coal-bearing series. Elsewhere there is evidence that the conglomerate as originally laid down has been disturbed: the boulders have been washed out and carried to a distance, where they have been again consolidated into a stratum. Such a remade bed is said to be *rémanié.*

The Coal-measure Series.—Above the conglomerate there are coarse sandstones and shales with coal seams at the base. The sandstone is of the Idutywa type, white and fairly loose in texture, and is used for building stone as in the Free State. The coal occurs in seams up to 20 ft. in thickness. It is often covered with boulders from the Dwyka Conglomerate, and the sandstones above occasionally include numbers of such boulders, clearly indicating land conditions, so that we must assume a considerable break between the Coal-measure Series and the Dwyka Conglomerate. There is no correlation between the Transvaal coal beds and the carbonaceous shales above the Dwyka Conglomerate in the Cape Colony. As far as one can judge, while the southern portion of the Cape Colony was occupied by a deep lake, the northern portion in the Transvaal was a swampy back-water surrounded by tropical forests which grew upon the boulder clay, and from these forests were formed the coal deposits. The coal seams are often broken by lens-shaped layers of sand, which are the deposits of streams which flowed through the marshes, and further prove that the coal was the result of growth in place of the vegetable matter of which it is composed, unlike the Stormberg coals, which are the result of the accumulation of drifted wood which became waterlogged and sank to the bottom of the water. Where the coal is near the surface, the water sinking through the coarse sandstones above has washed out the coal along certain lines, and the roof of sandstone, becoming thus unsupported, often falls in and causes deep pits to form on the surface. Some of the Transvaal coal, however, is of drift origin; solution channels in dolomite are sometimes filled in with secondary coal and coaly shale.

The fossils of the Karroo Beds in the Transvaal are the typical Triassic forms of the flora of the Southern Hemisphere, *Glossopteris*, *Gangamopteris*, and *Noeggerathiopsis* (*Cordaites*), and in addition there are lepidodendroid stems, *Sigillaria* and *Bothrodendron*. In the bed of the Vaal River, at Vereeniging, at very low water, there are exposed the stumps and roots of a number of large lepidodendron trees.

The thickness of the Karroo Beds in the Transvaal reaches a maximum of about 1000 ft.

The Stormberg Formation

In the north central portion of the Bushveld there are the so-called Springbok Flats Sandstones or Bushveld Sandstones, white, chalky-looking sandstones, in every way similar to the Cave Sandstone, and like it containing remains of dinosaurs. These are followed by amygdaloidal basalts which have been placed as contemporary with the Drakensberg lavas. The actual continuation of the Drakensberg is the Lebombo range, which consists of basalts and more acid rocks referred to as rhyolites. This range separates the low country of the Transvaal, made of Swaziland Beds, from the Portuguese territory, which is a sunken area covered with Upper Cretaceous deposits.

NATAL

The Province of Natal consists primarily of two portions: an elevated shelf along the coast made up of granite and Swaziland Beds, covered with Table Mountain Sandstone on the south, and with reddish sandstones and arkoses referable to the Waterberg System on the north, the whole further covered with Dwyka Conglomerate. The inland portion is the mountainous region commencing with the Dwyka Conglomerate, and followed by a reduced thickness of Karroo sediments with the coal measures, up to the Stormberg Formation, and finally, on the eastern border rising to the lavas of the Drakensberg. In Zululand there is the end portion of the sunken area covered with Cretaceous deposits which we saw in Portuguese East Africa, which includes St. Lucia Bay, and terminates at Port Durnford. South of the latter point the coast is bordered by the Great Fault, and only just over the border in Cape Colony do the Upper Cretaceous deposits appear at the Umzamba River. The Swaziland Beds are exposed along the deep gorges which the Rivers Umzimkulu, Umkomaas, Umgeni, Umvoti, and Tugela have cut through the overlying Table Mountain Sandstone or Red Sandstone respectively. Along the Umzimkulu, there are beds of limestone which have been invaded by the granite, as in Worcester, Cape Colony, but on a very large scale. The rock resulting from the contact is a coarsely crystalline white marble with many lime and magnesium silicates formed as a result of the invasion of the igneous mass.

The Table Mountain Sandstone is quite typical in the south, it is a coarse false-bedded sandstone, weathering greyish white, and usually lies fairly flat. The red Waterberg sandstones in the north are similarly laid, and the unconformity that should exist between the two sandstones has not yet been discovered. These two formations formed the surface of the land bordering the Karroo lake on the eastern side, and now form the basis on which the Dwyka Conglomerate rests. No glacial pavements have been found except in the Vryheid and Utrecht divisions, where the conglomerate rests directly on the Swaziland Beds and granite.

The Cretaceous beds of Zululand consist of gritty sandstones more or less calcareous, with clays and marls, containing corals, gasteropods, and a vast number of species of Ammonites and Nautilus. The beds are Cenomanian to Lower Turonian, and are therefore a little older than the Pondoland Cretaceous beds. Similar beds have been found in Sofala, German East Africa, and Madagascar.

Along the littoral in Zululand there are exposed at very low tide a series of beds, the bottommost of which consists of shales containing the bones of extinct forms of rhinoceros, elephas, and large antelopes. Over this is a series of shales with a few scattered bones and crustacean and fish remains. Above this is a thin layer of foraminiferal sand, and then a foot or so of shales containing Tertiary mollusca. On top there are some 100 ft. of false-bedded sands of various colours, covered by the Recent sand dunes.

DAMARALAND

On the east the whole country is covered with Kalahari sand with occasional patches of surface limestone, but towards the coast the older platform of South Africa appears. It is thinly overlain by Dwyka Conglomerate and the overlying shales with *Eurydesma* and *Conularia.* The shales are some 600 ft. thick, and contain a little limestone and micaceous, light-coloured sandstones. Besides the marine fossils mentioned, there are *Calamites* (*Schizoneura?*), stems and blocks of *Dadoxylon* wood turned into stone. The continuity of these beds with those of Cape Colony is doubtful. It seems rather that all the Karroo sediments formed north of the well-marked shore line, which runs through Prieska, were deposited in independent lakes or estuaries. Dolerite dykes and sheets occur in the Damaraland-Karroo beds as they do in Cape Colony.

Near the coast calcareous sands have been found in places which have been doubtfully referred to as Cretaceous: the fossils obtained are rolled casts and their identification is uncertain. It has been supposed that these Cretaceous sandstones received the wash from the diamondiferous country round Kimberley, and that, consequently, the agates and other peculiar stones found in the Vaal River gravels, together with the diamonds, became embedded in the sand as it formed. When the land rose, and these beds became exposed to desert weathering, their friable nature caused them to crumble; the wind, catching the lighter particles, blew them away to form the dunes of the sand belt, but the heavier agates, pebbles, and diamonds were left behind. Large areas of gravel swept clear of the sand by the wind occur in Damaraland, and constitute the diamond fields of German West Africa. The diamonds occur on the surface, and can be picked out by hand; they have all been, so far, of small size.

The platform on which the Karroo, Cretaceous, and Recent deposits rest is divided into two sedimentary series, which can be illustrated by the following table:—

Table of the Pal-Afric Rocks of Damaraland

Nama Formation.	Hanami or Fish River sandstones	= Waterberg System.
	Green shales and light sandstones	= Pretoria Series.
	Otawi limestone	= Dolomite Series.
	Huib or Kuibis quartzite	= Black Reef Series.
Primary Formation.	Chanse greywacke.	
	Orange schists, green schists, quartzites, and limestone.	
	Komas schists, thinly foliated gneiss, mica schist, limestone.	
Granite and Gneiss.		

The only series of which the correlation at present is tolerably certain is the Dolomite, which, being a deep-water deposit, was more constant in its characters; the more littoral deposits of the Black Reef Series would naturally tend to vary more.

RHODESIA

Rhodesia consists of a great tableland of granite, through which are drawn bands of schists folded in narrow belts in the granite. Remnants of the Dolomite Series and overlying Waterberg Sandstone are found near the Limpopo and near the Zambesi, but for the rest of the country none of these formations remain. A vast area of the country, however, is covered with Karroo Beds, with coal and the Forest Sandstone, which is the same as the Cave Sandstone, and in the north great outpourings of basalt occur equivalent to the Drakensberg lavas, such as those which form the lip of the Victoria Falls. The following is a list of the formations represented:—

Laterite, tufa		Recent.
Somabula gravels and Plateau gravels ...		Tertiary.
Tuli amygdaloid, Botoka basalts		Volcanic.
Forest sandstone, Samkoto Series	=	Cave Sandstone.
Coal Measure Series (Escarpment grits), Matobola and Busse Beds... ...	=	Idutywa or Beaufort Series.
Waterberg sandstone.		
Dolomite.		
Auriferous System.		Conglomerate Series with interbedded lavas. Banded Ironstone Series. Basement schists with intrusive granite.
Basement granite and gneiss.		

The Auriferous System is folded in the granite and is intruded by later granite. The basement schists consist of altered basic rocks (epidiorite), hornblende, and chlorite schists, which carry most of the payable quartz reefs. The Banded Ironstone Series is made of magnetite quartzites and ferruginous slates; often on the surface the quartzite is brilliantly white like lump sugar, and the brown iron ore in layers between the white rock gives the whole a striking appearance which miners have emphasized by applying to these ironstones the name of *calico rock.* The Conglomerate Series is similar to the conglomerates of the Elsberg or Ventersdorp System, and, like them, has volcanic rocks associated with it. It has been found to be auriferous in places, and is hence called a *banket,* that is, a conglomerate carrying gold. The Witwatersrand banket is made up entirely of quartz or quartzite pebbles, whereas the Rhodesian banket contains pebbles of granite and other rocks. It is of sedimentary origin, but volcanic agglomerates also occur,

Fig. 54.—Generalized Section from the Zambesi to the Limpopo (after Mennell)
1, Granite. 2, Schists. 3, Older sandstones. 4, Coal Measure Series. 5, Forest Sandstone.

and in addition conglomerates formed by the movement of rocks along faults, whereby the original fragments of the crush breccia are rounded, are also found; hence three types of conglomerate occur, each very similar in appearance and each carrying gold, but all three are of very different origin.

The Karroo Formation in Rhodesia consists of sandstones with some shales and rare bands of limestone, besides seams of coal which are thick and of good quality. It extends all through the north of Matabeleland, and southwards near the Limpopo from Tuli to the Sabi River. The only mine at present worked is at Wankies. The fossils of the series are freshwater forms, and include the fish *Acrolepis*, the little freshwater bivalve *Palæomutela*, *Calamites* (*Schizoneura?*), and *Glossopteris*.

The Forest Sandstone is a loose white sandstone with peculiar concretions of agate. It is an excellent building stone. The Batoka basalts, which follow, occur most prominently at the Victoria Falls; they stretch southwards into the Kalahari Desert, and westwards beyond the great bend of the Zambesi above the Linyanti Falls. On the east they are cut off by the great Deka Fault, which brings up against them the Matobola Beds with the Wankies coal seam.

The whole country is covered with superficial deposits either of concretionary limonite or *ou klip*, or of Kalahari sand with its accompanying calcareous or siliceous tufa. True laterite does not appear to be common. The plateau gravels occur far above the present levels of the rivers, and often contain diamonds, as in the Seta gravels on the Limpopo, which is an interesting occurrence as affording an instance where true ruby and true jade occur together with the diamond. In the Somabula Forest the gravels are even richer in gem stones. The matrix consists of rounded pebbles of quartz, banded jasper, agate, quartzite, silicified wood, granite, and chlorite schist, cemented by ferruginous sandy clay. In this there are found diamond, ruby, sapphire, beryl, chrysoberyl, topaz, garnet, staurolite, andalusite, kyanite, zircon, and tourmaline. True diamond pipes of the Kimberley type also occur on the Bembezi River.

CENTRAL AFRICA

The determination of the strata in Central Africa is at present impossible, owing to want of information. There is always the great granite basis with gneiss, schists, and occasionally limestone folded in or intruded by the granite. Above this is a thick series of coloured sandstones and flags which have been correlated with the Table Mountain Sandstone, but which are more probably Waterberg Sandstone. These are found in Nyasaland (Mafingi System), in German East Africa, and round Lake Tanganyika (Old African Sandstones). In Nyasaland the series is fully 10,000 ft. thick, and in the same country it is followed unconformably by an immense thickness of Karroo Beds, which, remembering the thinness of the system in the Transvaal, indicates that here an entirely separated body of water was receiving sediments.

TABLE OF THE KARROO BEDS IN SOUTHERN NYASALAND
(A. R. Andrew and T. E. S. Bailey)

	Approximate Thickness in Feet.
6. Uppermost division of pebbly sandstones, found only in Portuguese territory near Sinjal ...	200
5. Lava Series with interbedded sandstones	5,000
4. Upper Sandstone Series—massive sandstones or grits, often pebbly, with fossil wood	10,000
3. Shale Series—sandstones, black and grey shales and mudstones, with thin seams of coal and ironstone. *Glossopteris*, *Schizoneura*	4,000
2. Lower Sandstone Series, similar to the Upper Sandstone Series, but more conspicuously current-bedded	6,000
1. Boulder-bed Series—boulder beds, black carbonaceous shales with streaks of coal	450

In the north of the lake the Karroo Beds consist of blue and grey shales resting on the tilted Old Red Sandstones of the Mafingi Series; these are the Drummond Beds, and contain scales of ganoid fish.

CONCLUDING REMARKS

The student who wishes to pursue the study of geology further is advised to read Sir Charles Lyell's *Principles of Geology.* The book is out of print, but secondhand copies usually can be obtained. It is the only work yet written which gives fully the philosophy of the subject. Prof. J. W. Judd's edition of Lyell's *Students' Elements* is a good standard textbook. Larger ones are Sir Archibald Geikie's *Textbook of Geology* and the magnificently illustrated *Geology,* by Professors Chamberlin and Salisbury, either in the single-volume edition or the three-volume edition. For South African geology there is Dr. A. W. Rogers's *Geology of Cape Colony*, and Drs. Hatch and Corstorphine's *Geology of South Africa.* The student would do well, however, to obtain the publications of the Geological Survey of Cape Colony and of the Transvaal. Geological maps are issued by these, which can be obtained at a reasonable price. The South African fossils are published in the very fine series of memoirs issued conjointly by the South African Museum and the Cape Geological Survey. Other publications that should be consulted are the Transactions of the Geological Society of South Africa, Johannesburg; the Transactions of the South African Philosophical Society, now the Royal Society of South Africa; the Annual Reports of the South African Association for the Advancement of Science; and the Records of the Albany Museum, Grahamstown. The standard geological magazines, in which articles on South African geology are constantly appearing, are: the *Quarterly Journal of the Geological Society*, London; the *Geological Magazine,* London; the *Journal of Geology,* Chicago; and the *Zeitschrift für praktische Geologie,* Berlin. A bibliography of books and papers on South African geology was published by Mr. H. Saunders, and a much larger one by Miss Wilman.

The student should obtain the *Advanced Atlas for South African Schools,* T. Nelson & Sons, where all the necessary maps, topographical and geological, are given.

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